A MODEL FOR PERFORMANCE MANAGEMENT IN REAL PROPERTIES USING STATISTICAL TECHNIQUES

by

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Bachelor of Architecture
School of Planning and Architecture
New Delhi, 1984

Submitted to the Department of Architecture
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ABSTRACT

Within Real Property Portfolio Management, there is a conscious search for new methodologies to improve building management practice, particularly for facilities in-use. An approach in this direction is realized by the application of Statistical Quality Control (SQC), a technique used for monitoring quality in industrial products. This thesis presents a framework for performance control of real property portfolio, based on the principle and practice of SQC.

The model has three primary constituents: information, techniques and rules. The model uses data generated from building operations activity of maintenance and repair. The usage of non-monetary information to assess performance of buildings is one of the key features of this model. User generated information, such as complaints, originating from various sources within the portfolio, are used as indicators of performance. Two groups of statistical techniques are used in the model; the first uses historic operations data for defining management priorities in the building inventory, and the second utilizes data generated from current maintenance and repair activities. The rules determine the practice at different levels of the organization, with particular illustration for operations level.

To understand various organizational issues brought forth by the model from the point of view of an existing facilities management organization, a case study is undertaken of the Physical Plant Department (PPD) at MIT. PPD governs the operations of MIT's academic portfolio; it is primarily engaged in providing day-to-day building services to the MIT community. The model is then tested for performance control of the roofing sub-system by utilizing the operations information collected by Physical Plant Department from 1980 through 1988.

The implications of assessing building performance in "statistical terms" are enormous. This thesis is aimed at understanding various organizational pre-conditions that apply for accepting the SQC model in order to improve building management practice.

Thesis Supervisor: Ranko Bon.
Title: Associate Professor of Building Economics and Technology.

For
AAI AND BABA

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CHAPTER 1

INTRODUCTION

1. 1 THE INTENT

Within Real Property Portfolio Management (RPPM), there is continuous effort at improving building management practices, particularly for performances of buildings in-use. Methodologies that have recently emerged in this direction have robustly utilized knowledge generated from building operations. While some of these are simple management control techniques, others make use of more sophisticated models in operations research and advanced statistical techniques. Regardless of the level of sophistication, these methodologies suggest that systematic analysis and feedback of the historic building operations information, yield improvement in not only performance of buildings in-use, but also benefit other parts of the building process.

Performance management is stated as a framework within which the pertinent quality characteristics of a building, sub system or a component is monitored and controlled, such that they fulfil the intended function of the user. In the context of real property portfolios, performance management implies two things; firstly, that all buildings in a portfolio should fall within some specified range of "mean" performance and secondly, the "mean" performance in the portfolio should subsequently increase with improved performances management practices.

To achieve a uniform level of performance is the functional objective of all facility management organizations. The deviation from mean level of performance occurs primarily due to two kinds of problems in buildings. These problems are similar to the notion of "sporadic" and "chronic" defects found in manufacturing products (Juran, 1974, sec. 2, p.15). Performance management implies a collective approach towards controlling both kinds of performance problems in buildings.

The first kind of problem to which performance management is applied are variations in building/ component that occur because of the operations process itself. Some variations that occurs in the process are sufficiently large to attract supervisory attention. Others, may be deemed insignificant and thus ignored or deferred. Control is achieved by activating building operations activities, such as maintenance and repair, to achieve status quo. Control is implemented at the operations level of the organization. A "mean" level of performance is achieved through a systematic feedback of information generated from operations at a particular point.of the process. The types of analysis required to establish status quo are simple techniques to be utilized at the operations level. One major source of this information are users, who via complaints, inform management about variation in building performance, within institutionalized procedures that allows this information to be received, recorded and acted upon. In the absence of such a framework, organizations use other methods for gathering information about variation in performance.

Performance management is also applicable for controlling another kind of problem, those arising due to "chronic defects" (ibid, sec. 2, p. 15). Symptom manifest themselves in "trends" in performance variations and exist before the point where the process goes out of control. In most cases, operators and management are not aware of the persistent nature of the problem, which often leads all concerned to accept it as unavoidable (ibid, sec. 2, p. 15). The types of analysis required to solve chronic problems are in-depth inquiry of historic performance data by using advanced techniques, for e.g. experimentation, in order to achieve new performance levels. Data planning for such tasks is specially designed and decision-making action takes place at the upper levels of management.

This thesis is aimed at outlining a model in which Statistical Quality Control (SQC) techniques are applied for performance management in real properties. The emphasis on this study is on developing appropriate tools that allow for performance control in buildings, for the first kind of problem described above. SQC is applied largely within the manufacturing industry, whereby quality of products produced or purchased is controlled by statistical sampling routines. In its simplest model, SQC is measuring performance attributes on a sampling basis to determine whether they confine within the range of control limits—previously determined by the organization—and subsequent management action based upon these observations. The steps that roughly outline the SQC technique is given below:

a. Defining quality quantitatively;

b. Selecting attributes for measurement;

c. Processing data obtained for the selected attributes using statistical techniques;

d. Comparing actual performance with target; and

e. Management action based on the initial definition.

This framework, stated above, can be adapted for monitoring quality of performance in buildings within a portfolio. In RPPM the utilization is, for controling performance of an individual facility, and at the same time for providing management with a good measure of the overall performance of the portfolio. This approach, however is only valid if buildings are considered, not as isolated objects but as a "stream of services" provided for its users. In this context, RPPM provides the theoretical and institutional framework for the model.

RPPM itself has evolved out of the effort to bring together various discipline of the building process—physical management, financial management, and organizational use, under an organized strategy applicable across the portfolio. It merges the traditional roles of Real Estate Development and Facilities Management, under one corporate strategy. The performance focus of RPPM for physical management includes efficiency of operations and life cycle. To achieve these performance goals for physical management, there is a continual effort towards developing tools that are simple in use, economical and easily incorporated into existing the organizational procedures. The use of SQC in RPPM is suggested by the following factors:

Firstly, a hundred percentage monitoring of performance in buildings is impossible, both physically and economically, particularly in cases of large and complex facilities. A selective approach developed on a scientific basis will enable the management to concentrate only on those critical items in the building inventory, adjudged appropriate by the performance indicators. Similarly, any quality improvement programs to achieve 'breakthrough" in quality with an aim to establishing new performance levels, can be economically justified to be these few buildings.

Secondly, performance characteristics in building are in a constant state of flux. The change in state is a result of: continuous weathering and wear and tear of the physical structure of the building; changing user requirements; and constant developments in policy, and organizational changes in facilities management organization. As a result, facility management personnel require a major effort to constantly keep track of changing performance characteristics.

SQC as a tool for performance management is aimed for use at different levels of the organization and at different stages of the building process. The study emphasizes its use for performance control of buildings, through on-going operations activities, however other potential uses of this model are not excluded:

For Building Operations: At present, a large part of maintenance and repair work within a facilities management organization is being carried out as a direct response to user-complaints or specific work requests. Preventive maintenance is carried out only for some items in the building inventory. Operations activity is largely "responding/ directing" functions, concerned with fulfilling day-to-day tasks. The model provides the operations level, with appropriate tools for guiding management action.

Guides for Policy Decisions: This is particularly important for strategic allocation of resources for maintenance and repair, deferred and maintenance practices. The models allows the management to get a good picture of the state of operations process, at the same time highlights the building/ systems/ components that need quality improvement programs. Decision-making can be based on comparing performance indicators, both vertically and horizontally across the portfolio.

Design Feed back: Apart from managing existing buildings, RPPM also deals with acquisition and construction of new facilities. Design-feedback is recognized as an important area of application which entails a process of systematic learning from knowledge acquired through problems encountered during building maintenance and observations of buildings in use. (Fagg, 1987, p. 223) The value in this process is that it effectively captures institutional knowledge of performance specific to the building operations, organization and policies, of the facility. Institutions can capture the existing know-how in an efficient and organized way by way of these performance indicators. This can further become grounds for communication with designer of new facilities in the portfolio. (Ventre & Ghare, 1987, p.2)

The incentive for a facilities management organizations to adopt this model can be emphasized on the basis of its economy, practicality, and simplicity. The factors stated below should present an incentive for any organization whose focus is to improve management practice.

a. The cost of implementing this model is minimum.

b. A large proportion of the information required for the model is already collected by the facilities management organizations through their routine operations. It can be easily superimposed within the existing structure and work procedures of the organization.

c. It is simple to use andeasily communicable, as many of the techniques are graphical in nature. Some training in basis statistics may be required in order to appropriately interpret the SQC techniques.

d. It is geared for a diverse set of users within the facilities management organization.

1.2 STRUCTURE

The structure of the thesis is in progression from the theory of SQC to its application for roofing sub-system. The transition occurs in the thesis subsequently in the following four chapters. A brief description of the topics covered in each chapter is given below.

The first chapter introduces various themes that run throughout this study. The theory and application of SQC in manufacturing and non-manufacturing industries is introduced.Then, Hashimoto's (1984) adaptation of SQC for construction is discussed to identify the commonality in the adaptation process. This is that the first adaptation of SQC from manufacturing to any stage of the building process and an understading of this is relavant.

The notion of quality and quality control in the building process is also discussed in this chapter. Quality in the building development process is acheived by controlling the critical attributes at each stage of the process: at the design stage, quality control is built in the architectural requirements, engineering considerations and the choice of building materials; at the construction stage, it is achieved by monitoring and controlling the construction process and minimizing deviation from "as-planned"; and at the operations stage, quality is achieved by monitoring the ability of the building component to satisfy their specified performance criteria. Feigenbaum (1983, p. 7) has defined quality as the total quality product and services characteristics through which the product and services in-use meet the expectations of the customers. The key concept in this definition is that perception of quality is with the consumer/ user of the product. In a real property portfolio, the concern for quality of performance stems from the management's goals to meet two aspects of quality; firstly ensuring that building components meet the specified performance criteria, and secondly, to provide its customers with building services in the most efficient, economical and productive manner.

The first chapter also argues that RPPM is an appropriate institutional framework for application of the model. RPPM provides an organizational structure for better interface with the user-end of the facilities, and secondly, a collective database of operations information generated across the portfolio, for which statistical methods can be applied.

The second chapter describes an outline of the SQC model for performance control and discusses the three elements of the model — information, technique, and rules. The vitality of information generated through utilization and operations phase of the building is analyzed in the context of its uses for statistical purposes. Ashworth & Au-Yeung (1987, pp. 141-143) point out that historic data required for statistical purposes in order to identify trends in performance is either unavailable, incompatible or insufficient. All three states arise out of either data collection procedures, variability in buildings, maintenance processes, and organizational policies and procedures. The recognition of variability in data is important, for it not only needs to be accounted, but also in order to highlight ways in which future data collection procedures may be improved.

The definition of quality involves the user's perception in an important way. Most large facilities management organizations utilize actively, user-generated information of performance information for feedback and control. This thesis recognizes user -complaints as an important indicator of building performance. This implying that an indirect relationship exists between the complaints and performance. Thus, as the performance of the building increases, the number of complaints reduces. Theoretically, building performance is maximized in the absence of any complaints. The reliance of complaints to control performance by facilities management organizations is because users are sensitive to immediate changes in their physical environments. The concern for the management in reducing the number of complaints received implies, a commitment for providing standard performance level.

The statistical techniques outlined in the model are grouped in two parts. The first uses historical data, in order to establish priority areas, isolate the "outliers", establish correlations between different performance characteristics, and to identify trends in performances. The second group uses data generated through current building operations for monitoring performance variations, through techniques such as control charts. The search for the appropriate "control subjects", brings forth many important issues particular to the adaptation of SQC for performance control. The first is relates to prioritizing the performance charecteristics that need to be controlled, based on management needs and the amount of data available at any given time. The second issue concerns the choice of appropriate performance measures for quantify performance charecteristics.

The development of the model for performance management, required three kinds of knowledge. First, a thorough understanding of building operations process; the collection and flow of information, the information needs of various functional units, decision-making processes, interdependency between different functional units, etc.. Second, information is required in sufficient detail over considerable time-span for a group of buildings under the same management control. And lastly, some understanding of basic statistics concepts for appropriate use of the techniques.

This thesis uses an existing facilities management organization as a case study to understand some of the organizational issues brought for by the model, from the point of view of an existing organization. A case study in umdertaken in chapter four of the Physical Plant Department (PPD), at MIT. PPD governs the operations of the academic portion of MIT's portfolio. The model is applied for performance management of the roofing sub-system for the academic buildings, under PPD's charge. The data used for this application, was collected by PPD from 1980-1988 from historic operations records. The primarily reasons for choosing PPD at MIT are discussed below:

Firstly, information required for statistical purposes is adequate and easily accessible at the PPD.

Secondly, the academic portion of the real property portfolio comprises of 127 buildings on the campus. Operations of these buildings are under the same management and subjects to similar operating procedures, maintenance policies and administrative practices.

Thirdly, buildings on the campus are in same geographic proximity, and subject to similar climatic conditions, usage, etc.

The methodology applied in the case study is through investigation by the author. This also entailed field observations of on going building operations and extensive interviews with the staff and management at various levels of the PPD. The primary focus of the study was the operations center, centralized location of receiving, recording and transmitting buildings operations information. Study of the operations log-book yielded subsequent information about the types of performance problems highlighted by day-to-day activities of maintenance and repair.

Roofing was then identified as a potential sub-systems for the application of the SQC model for performance control. The roofing sub-system constitutes one of the largest cost component in any facilities organization, primarily because it is one of the most severely exposed parts of the building envelop. In recent analysis, it has been pointed out that the cause-effect relationship of roofing problems is indeed critical, and warrants management attention for improving performance. Chapter five illustrates the application for performance management of roofing sub-system.

The implications of assessing building performance in "statistical terms" are enormous. At a theoretical level, SQC can be applied for controlling the quality of either the process, factors of production, and/ or the product itself. However, many pre-conditions apply for appropriation of the model. The aim of the thesis is to highlight and understand these issues for the development of this model.

CHAPTER 2
STATISTICAL QUALITY CONTROL: THEORY & APPLICATION

This chapter introduces three topics; first Statistical Quality Control (SQC), its theory and application for controlling quality in manufacturing products and other industries is discussed in order to understand the common grounds for adaptation. Second, concepts of quality control within the building development process is discussed, and lastly, Real Property Portfolio Management (RPPM) is introduced as a conceptual framework for applying SQC for performance management.

2.1 STATISTICAL QUALITY CONTROL

2.1.1 INTRODUCTION

The institutionalization of quality in products came about essentially at the advent of industrialization. As products became increasingly complicated and labor specialized, it was necessary to develop measures to inspect products after manufacturing. However, it was only in the late 1920's and after the development of an exact theory of sampling that statistical techniques were systematically applied to Quality Control (QC).

The use of statistical techniques for controlling product quality was first introduced in 1924 by W.A. Shewhart of Bell Telephone Laboratories. He developed a statistical chart for the control of product variables. Later in the decade, H.G. Dodge and H.D. Romig, developed the area of acceptance sampling as a substitute for 100% inspection. These twin concepts - of control charts and acceptance sampling--laid the foundation for Statistical Quality Control (SQC). The rate of adoption of statistical methods in the manufacturing industry, as means of controlling product quality was particularly slow. After World War II, and more enthusiastically in the 1940's and 1950's, SQC became synonymous with quality control. The proponents of the SQC movement publicized it so widely that many managers gained the impression that quality control consisted of using only statistical methods. This view dissuaded the use of quality control as a regulatory process. Furthermore, the recommendation resulting from statistical techniques could not be handled from within the decision-making units such as the inspection group or the quality control coordinator, and without the support from the top management. (Feigunbaum, 1983, p. 16) A counter-movement in the late 1950's took place, aimed at de-emphasizing the limited approach of SQC and restored the notion that a broad collection of tools are required for QC, within total quality framework under "Total Quality Control" (TQC), of which statistical methods is but one sub-set.(Juran, 1974, sec. 2, p.12)

Feigenbaum (1983, p. 345) points out, that the early reluctance to SQC was "in part because of the natural resistance to the introduction of new and unfamiliar methods and more specifically because of the factory supervisors "distrust of mathematical symbols" and "in part due to the overabundance of technical statistics and underabundance of practical administrative applications." He further adds that the later acceptance of SQC can be attributed to "a surprisingly large number of employees trained for statistical methods," the availability of computers, advancements in data-processing equipment, and successes in practical application of SQC by industrial management.

An important aspect of SQC, as practiced in TQC, is that it does not represent "an exact science. " It is often quoted in various literature on this subject that "effective SQC is 10% statistics and 90% management action." The successful application of any statistical model is strongly influenced by human relations factors, technological conditions, and cost considerations. (Feigenbaum, 1983, p. 346)

2.1.2 SQC IN MANUFACTURING

In today's practice, SQC is understood as a branch of TQC which relates to the collection, analysis, and interpretation of data to solve a particular problem of product quality. TQC itself, is a regulatory process, through which actual quality performance is measured, compared with standards and action based upon the difference. From an industrial viewpoint, variation in products quality must be studied constantly: within batches of products, within processing equipment, between different lots of the same article, for critical quality characteristics for existing products, and for newly designed samples. The variation is studied by drawing samples from the product lots or from units produced by the processing equipment (Feigenbaum, 1983, p. 605). The predominant techniques used in manufacturing application are: frequency distribution, control charts, sampling tables, special methods, and reliability analysis.

Juran (1974, sec.2, p.11) defines the process as a series of universal steps, applied to the problem of product quality. The mechanism that carries out this universal series of steps is the feed-back loop. The steps involved in the SQC process are:

a. Defining quality quantitatively.

b. Selecting the "control subject"

c. Measuring the required data for variables that affect quality

d. Applying appropriate statistical techniques.

e. Comparing actual performance with target.

f. Management action based on the initial definition.

2.1.3 NON-PRODUCT APPLICATIONS OF SQC

SQC has been applied to a whole range of industries; product-based (such as household appliances), process-based (e.g. metal fabricating), service-based (e.g. hotel). Juran (1974, sec. 1, p. 5) refers to the question of adaptation of statistical techniques, originally developed for mass production manufacturing, to other industries:"Making this transition requires that he (the practitioner) identify the commonality, i.e. the common principles to which both his special situation and the derived knowledge correspond...Commonality of a statistical nature is even easier to grasp, since so much information is reduced to formulas which are indifferent to nature of the technology involved."

Adaptations in other industries which are diverse in product, process, materials and underlying technology, are resolved by identifying the universal factors that contribute towards achieving quality. The successful adaptation has been in cases where the principles of SQC have been clearly expressed. For example, an acceptance sampling scheme was adapted to the problem of checking errors in clerical work and similarly for checking of annual merchandise inventory in a department store. (ibid, pp. 618-622)

Within the building industry, statistical techniques have been applied for both, construction quality control (Hashimoto, 1986), and performance control of buildings in-use (Ventre & Ghare, 1987). Performance control is achieved by monitoring the various factors affecting quality at the utilizations and operations phase of the building industry. Building operations is by and large a service industry, where various agents — owner, building manager, contractors, vendors — are dominantly engaged in supplying demands of services generated through use, wear and tear, changing requirements and standards. Quality Control can be applied to buildings in-use based on the common grounds as follows: (Juran, 1974, sec. 47, pp. 13-14)

a. Managerial processes, i.e. policies, objectives, plans, organization, motivation.

b. Parameters of quality or "fitness of use".

c. Functional activities through which quality is achieved, such as planning, vendor relationships, use, maintenance, feedback, etc..

d. Universal skills, tools and techniques used in operations.

Grant & Leavenworth (1972, p. 618) point out two important differences between manufacturing and non-product application of SQC. Firstly, quality characteristics in manufacturing products have a definite tolerance limits, which is sometimes difficult to establish in non-product applications. Secondly, the selection of the appropriate variable in non-product cases require considerable imagination. For example, in one non-product application of SQC, the control variable was the difference between estimated performance time and actual time for many component operations on a critical path scheduling (ibid, p. 618). Numerous examples of non-product applications are found throughout the literature, that concern with finding appropriate measures of quantifying quality characteristics.

2.2.4 SQC IN CONSTRUCTION: A CASE STUDY

The effort of the construction industry, in the last decade, has been geared towards monitoring and controlling the quality of buildings under construction. The adaptation of statistical techniques for QC for construction has been slow, despite that it has borrowed, time and again, several industrial management techniques to achieve cost efficiency, process improvements, and increased productivity.

Some factors that contribute to the lack of endorsement for SQC are: firstly, the lack of substantial data for statistical processes in the construction process, due to the fact that buildings as product are still custom made. Secondly, there is a lack of skilled personnel on site for undertaking systematic quality analysis. Furthermore, most sites are not equipped with measurement tools for collecting data on site (Hashimoto, 1979, p. 33).

Yoshitsugu Hashimoto (1987), has presented in his book, *Improving Productivity in Construction Through QC and IE*, a case for adaptation of SQC techniques for construction. Hashimoto shows that SQC is a viable tool for the construction industry for reducing cost and improve productivity. This book presents the closest adaptation in the context of this thesis.

Hashimoto uses the Deming Circle, a five step approach to improving quality in construction by using various statistical techniques. The basic steps that outlined are: setting standards, implementing them, checking to clarify problems, correcting mistakes, and institutionalizing such that mistakes do not occur. Some of the important features in his adaptation, are discussed below.

Firstly, the starting point in Hashimoto's model is the target of QC, as those quality characteristics, which trigger customer dissatisfaction or complaints. The complaints received from field performance of the product (in this case, of pre-fabricated homes), is used to identify the quality characteristics and the basis of data collection.

Secondly, Hashimoto (p. 33) clearly defines the kind of construction works for which SQC can be successfully adapted. He emphases that the fundamental for the successful adaptation of SQC:"...considerable quantitative evaluation is possible if quality control is targeted not at units of construction work but at materials, methods, design specifications and other factors affecting quality."

The implication is that SQC can be successfully undertaken for those quality characteristics within the process, product or materials, that generate data that can be collected and measured specifically. Examples of applications of SQC cited by Hashimoto (pp. 33-34) are: quantities or amounts of materials at the time of purchase; the water or moisture contents of the cement, mortar, or other moisture containing materials; the hardness and elasticity of concrete; the depth of excavation, thickness of sprayed coating, thickness of concrete foundations and other characteristics of a finished project; the number of flaws per building or structure; number of complaints, and other such items that can be counted.

Thirdly, Hashimoto (p. 35) discusses data required for SQC with reference to its potential sources, methodology of collection and manipulation. Data sources can be both — a single large project, or a multiple construction projects. In a large single project such as high rise buildings, there are many individual, repetitive tasks (such as attaching precast concrete panels, floor finishing etc.) extending over a period, of time that would yield substantive amounts of data required for statistical purposes. Data for repetitive tasks can be easily obtained for each day, each location, and each sub-contractor.

Fourthly, Hashimoto (pp.39-46) demonstrates SQC as a tool for controlling quality of on-going construction. This is achieved by; formulating target standards; collecting data of required quality characteristics, generated on-site; analysis of variation, and taking remedial action to achieve target conditions.

Some of the success for the adaptation of SQC for construction as presented in Hashimoto's analysis can be attributed to the general characteristics of the Japanese construction industry itself. Westney (1987) analyzes the extensive similarities between the manufacturing and the construction industries in Japan. These similarities, discussed below, contribute greatly to the adoption of various industrial management science techniques such as SQC, operations research:

Firstly, there is perception, within most construction firms, of a building as a "product" ("product" here implies not only buildings, but also services). Thus, buildings are subjected to the same process — of product development and QC, as are consumer and other industrial products. Secondly, "there is a high-level of internalization of activities along the value-added chain." (p. 7) For the General Contractor, this means undertaking new types of works — maintenance, operations and renovation of their projects, allowing them to move into areas where there is interaction with the users of the "product". For example, the Japanese prefabricated home manufacturers provide peripheral services, including interior design, home maintenance and repair, enabling them to supply a warranty on their buildings (Mathieu, 1987, p.2), as in case of industrial products. The integrated approach results in a process that systematically collects customer information, analyzes it, and integrates the information into product development strategies. (Westney, 1987, p.10)

Hashimo's adaptation illustrates two important factors. Firstly, that an institutional framework is required for conducting quality program, that allows systematic evaluation and identification of the improvement areas, data collection, and feedback. Secondly, SQC is applied to those quality characteristics of either, methods, machines and/ or processes that can be easily quantifiable, measurable, similarly to its application in manufacturing.

2.2 THE NOTION OF QUALITY

Before any discussion of the SQC process can be undertaken, the underlying notions of quality and the quality control process need to be discussed. The concept of quality is strongly rooted in its association with "fitness for use". This term describes the extent to which a product can successfully serve the purpose of the user, during its lifetime. Fitness for use is the resultant of some well known parameters, based on quality characteristics, i.e."any feature, (property or attribute, etc.) of the product, material, or process which is needed to achieve fitness of use" (Juran, 1974, sec.2, p. 4). Quality of a product is thus defined as having the right features; which may be those specified explicitly by a customer, directly or by reference to some acknowledged specification, or may be implicit and mutually understood.

Quality characteristics are broadly categorized into three parameters: quality of design, quality of conformance, and quality of performance. This classification is designed to highlight the nature and interrelations of major economic forces involved between the user, manufacturer and the product; and for a more precise definition of the need of the users. (Juran, sec. 2, p.4)

Quality of design is a technical term that defines the stringency of the specifications for manufacturing of the product. Quality in design is achieved by implementing a three-step process which involves: (ibid, sec. 2, pp. 4-5)

a. Identification of what constitutes fitness for use;

b. Choice of the concept of product or service to be responsive to the identified needs of the users, and

c. Translation of the chosen product concept into a detailed set of specifications, which if conformed to the design, will meet the needs of its users.

Quality of Conformance defines the extent to which the product conforms to the original design requirements. Lack of quality of conformance is the resultant of numerous variables such as machines, tools, supervision, workmanship, etc.

Quality of Performance depends on both the quality of design and quality of conformance. Quality of performance requires a continuous feedback of quality information, to act as the basis for decision-making regarding the optimizing of a quality product. Various agencies are involved in realizing this feedback loop, within and/ or outside the organization.

The manner in which quality is organized and achieved for a product depends upon the characteristics of its base industry: the size of the industry, whether mass producing or craft-based, kind of industry- product, process or service, the product procurement process available to the industry, and the underlying technology. These factors are exemplified in the comparison of the organization for quality in the manufacturing industry and the construction industry: in manufacturing, one firm markets the final product- taking responsibility for design, selection and acceptance testing of components, internal quality control, packaging, preparing of instruction manuals and technical literature, product service, etc.. (Atkinson, 1987, pp. 3-4) In construction, the responsibility of the procurement and delivery of a product, whether a building or any other constructed facility lies with a team of agents organized specifically for the project.

2.2.1 THE "TIME FACTOR" IN REAL ASSETS

At this stage, a distinction is warranted between quality in products such as consumer products and real assets. The parameters of quality of design and quality of conformance are largely sufficient to determine the fitness of use in consumer products.(Juran, 1974, sec 2, p. 6) While considering the quality of real assets, several time-oriented parameters such as availability, reliability and maintainability, come into play.

Availability established the continuity of the product; a product is made available when it is in an operative state. Mathematically, it is expressed as a proportion of the uptime (operative time) to the sum of uptime and downtime (non-operative time).

Reliability is the technical term that defines the freedom from failure.

Reliability in products is largely determined by the quality of design. The movement to quantify reliability is thrusted by its scientific basis to predict, apportion, plan, achieve, test, control, improve long-lived products.

Maintainability is a term adopted to establish the ease at which maintenance can be conducted. It is stimulated by the need for improving the availability of the real product over its useful life. Maintenance takes place in two major ways, preventive or scheduled maintenance and routine maintenance. The effectiveness of maintenance is aided by the supporting technology; design for easy accessibility, modular replacement, easy diagnosis of the cause of failure, technical information about the product and its use, etc., all of which are considerations during the design stage.

In real assets such as buildings, these factors are of utmost importance. This is because the level of influence on future costs is highest during the initial design stage. This concern — to include reliability, maintainability and adaptability into buildings — is illustrated in the "terotechnology", a multidisciplinary approach to product development. Terotechnology is concerned with "specification and design for reliability and maintenance of plant, machinery, equipment, buildings, and structures with the installation and commissioning, maintenance, modification, and replacement with feed-back information on design performance and cost."(Philpott, July 1975, p. 76) Terotechnology developed in the early 1970's in United Kingdom, as a response to the problem of waste and and high cost of owning buildings. (Dell'Isola & Kirk, 1981, p. 7)

This approach emphasizes improved management of physical assets, as as result of feedback from operations of building to other phases of the building development process. The result of this total approach has led to the evolution of several feedback systems: i.e., techniques are now available to the designer which can help the process of assessment of space required for preventive maintenance in order to ensure the right degree of accessibility within a design. For example, three dimensional modelling tool are used to train design staff and building owner for understanding long-term implication of initial decisions, such as layout, re-arrangement of pipework connections, etc. on the costs and maintenance. (Philpott, July 1975, p. 77) The counter viewpoint to this within the construction industry, is that building regulations implicitly place timeless responsibility on the original designer/ producer for the "good performance" of the building, whereas performance characteristics are in a constant state of flux.

Maintenance is an integral part of the building; however successful feedback may be, there will always be a constant level of maintenance. This level of maintenance, is the target status quo in building operations, consistent with the degree of sophistication and economics of management.

2.2.2 QUALITY ISSUES IN THE BUILDING PROCESS

The delivery of the quality function throughout the building process has some important institutional concerns of its base industry. These factors are important for the understanding of the issues in the quality control process.

The building process involves many specialized agents: the owner, architect/ engineers, specialty contractors, contractors, sub-contractors, suppliers, vendors, building managers, etc. Within the building development process, design, construction and operations are still by and large separate and specialized activities. Design work is split between the architects and consultant, each having a contractual relation with the client. Actual construction work is sub-contracted, and then sub-subcontracted to individual trade specialists. And despite extensive contractual allocation of roles and responsibilities, there are many areas of works, for which no one assumes responsibility. Within this sequential process — of design, construction, and operations — systematic feed-back to the designers or the contractor about the performance or non-performance of the building is restricted.

Building as a product, is an assembly of manufactured materials, components, and mechanical equipments, installed on the site. Because of the craft-based nature of the industry, there is a high level of dependency of quality in construction on the individual skills and enterprise of the construction worker. (Atkinson, 1984, pp. 3-4) Furthermore, buildings are viewed within the industry, as unique products circumstantial to their location, function, design, usage, and management. Testing of prototype is rarely achieved even when designs are "standardized", because of the frequency of modification of details to satisfy site, regulations or user requirement.

One of the major criticism against the construction industry for lack of quality consciousness has been that process control is considered relatively unimportant in the light of the legal standards regulating the construction process and the inspection process conducted after completion. (Hashimoto, 1979, p. 4) The assumption here is that conformance to mandatory building codes, standards and other regulatory requirements are sufficient measures to ensure quality. These regulatory and inspection processes often cede to irregularities and inconsistencies, particularly in relation to quality.

2.2.3 QUALITY CONTROL IN THE BUILDING DEVELOPMENT PROCESS

Despite the inherent characteristics of the building development process, QC is applied as a regulatory process to building design, construction and operations. Quality in building process involves meeting the aims of the functional, economic and social needs of the users. It is achieved by controlling the critical variables affecting quality at each stage of the building process.

Planning and Design Quality Control: Two criteria are used in defining planning and design control. The first criteria is physical and economic control of the architectural and engineering characteristics of the building. This includes controlling factors such as the reliability of the initial brief; reliability of the design solutions for constructibility; reliability of the specifications/ performance criteria, reliability of the information used as basis of design, selection of products; and reliability of the calculation related to cost. (Hill, 1985, p. 90) The second criteria, relates to the realm of behavioral science which is concerned with achieving quality of constructed environments in relation to the socio-physiological, as well as physical needs of its users (who are in most cases unknown to the designer during the initial stages of the building process). (Peterson, 1974, p. 70-71) Planning and design QC emphasizes two themes:

a. Incorporating user requirements in the design: This is done by establishing a closer contact with customers and quantifying user needs in architectural and engineering terms.

b. Control of the medium of translation from design to construction. This is achieved by examining construction documents for clarity and completeness, and ensuring that drawings and specifications have no ambiguity, inaccuracies, that would lead to lapses in construction.

Construction Quality Control : Construction QC implies controlling the factors that cause deviation in quality in actual construction process. The construction QC process involves identification of the critical factor causing variation in construction process and taking remedial action. Thus, construction QC implies conformance to; drawings and specifications, organizational procedures, ensuring uniform skills between labor crews; performance of machines, etc.

2.3 BUILDING PERFORMANCE CONTROL

2.3.1 DEFINING PERFORMANCE CONTROL

Performance management is defined as an organized procedure or framework within which desired attribute of the building/ sub-system or component can be monitored to fulfill the requirements of the intended user/ s. The performance concept has been applied as a framework for building design; these are sets of rules or performance criteria defined at the start of the building design, for selection of the component. These sets of rules provide the basis for comparison and evaluation of the particular building systems throughout its useful life-cycle. However, such clear-cut comparisons of performance in building systems to its standards are rarely achieved and evaluation of building performance remains a consistent problem during the building cycle.

Building performances can be better understood from the vantage point of the economies associated with both the user and its owner. The value of the building is largely determined by the services it can offer to its users. Building owners derive their income by either, leasing its property to a tenant, self occupation. To the user of the building, quality is fitness for use, not conformance to specification. (Juran, 1974, sec. 4, pp. 2-5) Thus, in the absence of any demand for services, there will be no value to be maintained and is thus economically insignificant. The increasing cost of ownership, assumed to be twice that of the initial costs, requires that users optimize the economic value of the facility. The cost incurred during the operations and utilization phase of the building are as follows:

a. Operation cost, such as energy, fuel, supplies.

b. Maintenance and repair costs- housekeeping, replacement, etc.

c. Downtime resulting from building failures.

d. Depreciation of the building value due to wear and tear.

e. Loss of income, resulting from downtime.

In reality, these costs are not easily quantifiable in buildings. For example, many activities show a much higher degree of tolerance to their physical environment and thus these are unaffected by substantial changes in the condition of the building. (Lee, 1976, p. 52) Consequentially, maintenance cost for such activities are difficult to establish. Similarly, quantifying downtime cost resulting from building failure is obsure, unless there is a major mechanical system or building failure. Depreciation is more or less an accounting procedure within the building industry, and rarely considered to compute economic value.

Performance quality in buildings is defined by how well the building can respond to the availability and continuity of services over the building's useful life, at the same time optimizing its cost during operations and utilization. Availability and continuity of services can only be established if the physical structure of the building conforms to its specified level of performance. In this context, Lee (1976, p.52) suggests, that the effort of the management should be geared towards identifying those user activities that are sensitive to the physical condition of the building, and subsequently controlling the quality characteristics that play a significant role in providing the necessary conditions.

2.3.2 PERFORMANCE IN THE CONTEXT OF RPPM.

The first chapter has already introduced SQC as a viable methodology.that can be employed to achieve building performance control. The requisition performance control is an institutional framework within which the SQC process can be implemented. This institutional framework provided by Real Property Portfolio Management (RPPM) can be deemed valid: firstly, it provides an organizational framework and better interface with the user-end of the facilities and secondly, a collective database of information generated across the portfolio, for which statistical methods can be applied.

A real property portfolio can be described as a structured collection of buildings, together with the associated parcels of land, including land for future development. (Bon, 1989, p.123) RPPM has evolved with the effort to bridge the exiting gap between real estate development and facilities management. The organizational strategies in RPPM are arranged by three major disciplines, each with a distinct performance focus: physical management including all functions associated with facilities management; financial management, including acquisition, sale, disposition and other financial strategies; and organizational use which is concerned with space planning, inventory control, project management, shared services, etc. The performance focus in physical management is efficiency of operations and life-cycle cost; in financial management, the focus is on earnings, volatility and appreciation; and in organizational use, it is productivity, flexibility and satisfaction. (LAP, 1987 cited in Schcolnik, 1987, p. 16)

Within RPPM, there is a continuous effort towards developing better tools for evaluating real properties that are "outliers"; those buildings whose performance is the best or worst in terms of the performance parameters of stated above. The theoretical basis of RRPM, responds to methodologies using feedback of information to improve future performance of the portfolio as a whole. In this context, Bon (1989, p. 119) points out that:"The systematic learning process about the real property portfolio can inform several types of action available to the management. They relate to several phases of the building process. Those properties that perform best can be "replicated" by feeding information about their characteristics into acquisition of new buildings and redesign of existing buildings...In a sense, incremental improvement that is always in line with changing organizational objectives is the "theory" behind real property portfolio management."

The three parameters of quality in the building process - planning & design quality, construction quality, and performance quality are not exclusive parameter, but inter-dependent. However, systematic learning begins at the utilization and operation phase of the building process. It is through analysis of buildings in-use, that any theorizing about the performance of the buildings, sub-system or component can be made. SQC is a potential tool for evaluating past performances of buildings in-use and subsequently for applying this information to other buildings in the portfolio.

CHAPTER 3
SQC FOR PERFORMANCE MANAGEMENT

3.1 INTRODUCTION

This chapter explores some of the features of the Statistical Quality Control (SQC) model for performance management. These include; information, statistical techniques and management use of SQC for performance control. It has been argued in the previous chapter, that Real Property Portfolio Management (RPPM) provides the requisite institutional framework for the application of the model.

There are two functions of this model. The first function is for defining priority areas. These may occur; at the level of the portfolio for identifying the buildings that perform the best or the worst; at the facilities level for isolating the building sub-systems that need management attention; and at the operations level for identifying the assignable causes for variation in performance. The second function is for controlling quality of performance of either, a building, sub-system, or a component or the process itself, by continuous feedback of information generated through on-going operations activities of maintenance and repair.

Performance control in building operations is achieve through the feedback loop defined as a four-staged process.(See Figure 3.1) The first step in this process is setting performance standards; the second step involves taking actual performance measurements; the third step compares the actual and standard measurements; and the last step closes the loop by setting into motion the building activities that would restore the status quo. (Juran, 1974, sec. 6, p.11)

Towards the development of a model two kinds of knowledge are required. Firstly, an understanding of the process of building operations is essential

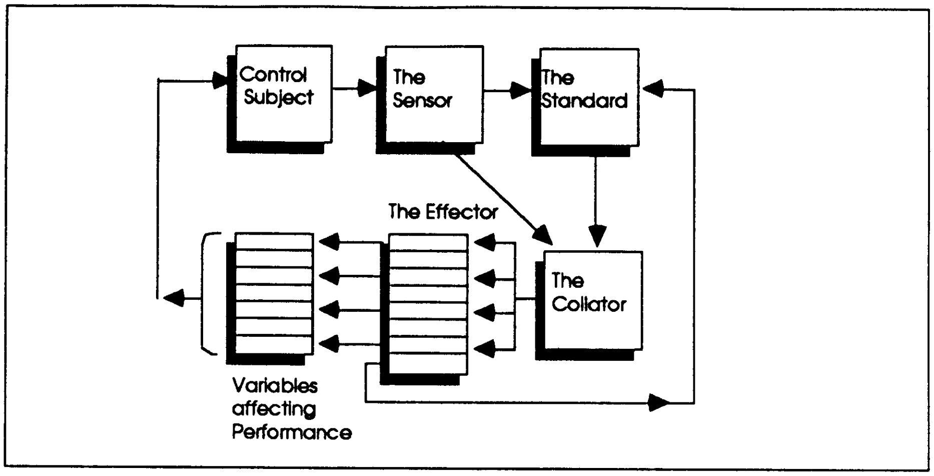


Figure 3.1: The Feedback Loop
Source: Juran,J.M., "Manegerial Breakthrough", 1964, p. 181

for the collection and flow of performance information, the uses of information by various functional units, decision-making processes, interdependency between different functional units, etc., and feedback processes. These factors are discussed in the next chapter, in the context of builing Operations at the Physical Plant Department. Secondly, a familiarity with the SQC process is essential such that it can be appropriated for performance control.

3.2 BUILDING OPERATIONS: THE PROCESS

During the utilization and operations phase of the building process, a variety of activities are simultaneously conducted to sustain the performance level of various building components/ systems. Building operations is defined as a day-to-day provision of supports and service functions that contribute to the successful mission of the organization. The factors that generate the need for maintenance and repair are: climatic conditions, user activities, changing organization standards, and user requirement. Building operations activities are typically organized in two categories--maintenance and repair.

Maintenance is the day-to day activity required to preserve or restore the facility such that it can be used for its designated purpose. Maintenance falls into two categories: scheduled or preventive and unscheduled or minor.

Repair is the restoration of facility to the condition such that it can be used for the intended purpose. Repair activities have three goals- prevent further damage, ensure safety of the facility, and provide that the facility may continue to used effectively with minimum interruptions (Russo & Williams, 1984, sec. V, pp. 24-25) Repair types may be further categorized as minor or major.

The procedure for identifying, prioritizing, and funding for maintenance and repair works differs significantly from one organization to the other. Both terms--maintenance and repair--are often used interchangeably, sometimes to justify the requests for funds, sometimes due to a genuine disability on the management's part to distinguish the type of work performed. In most organizations, these activities are collectively termed as "maintenance & repair" (M&R).

Other kinds of activity undertaken during the building lifecycle, in order to fulfil the performance requirement of the user or organization as a whole are: Renovations, which is total or partial upgrading of the facilities to higher standards. Alterations, which refers to the change of scope of the existing facility, and New Construction, which is the erection of new facilities in form of additions, expansions or extensions (ibid, sec V, p. 24.).

The organization for building services depends on several factors, such as the function, size and relative importance of an individual building or a facility (defined as a group of buildings), technology , etc.. Small physical plants may rely on in-house capabilities of a small unit of multidisciplinary staff capable of handling a variety of maintenance and repair jobs. Large physical plants typically supplement in-house capabilities by procuring outside services—of contractors, vendors, and trade specialists. The procurement process for outside services is organized similarly to the construction process.

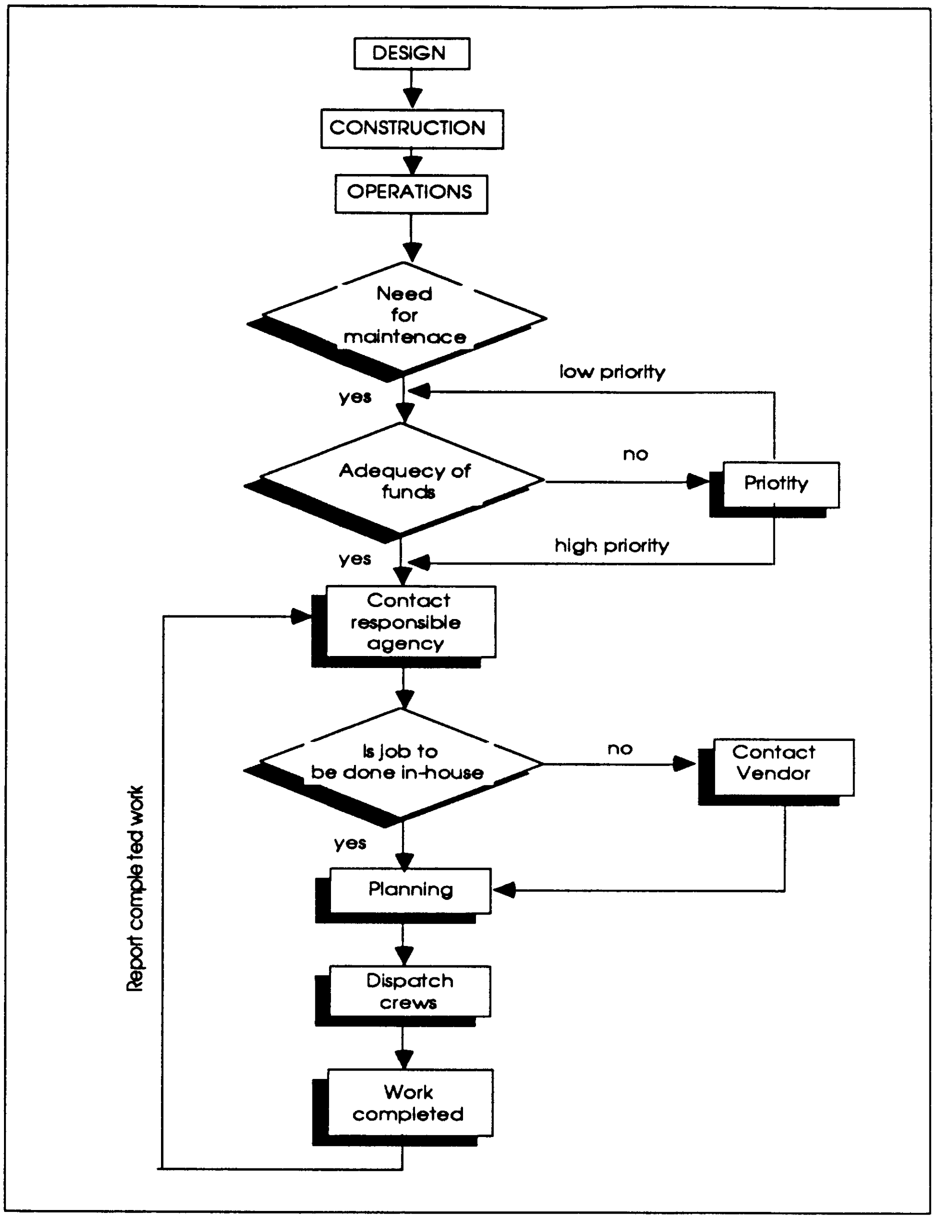


Figure 3.2: The Maintenance & Repair Cycle

Figure 3.2 shows a typical sequence of building operations activity and the decision making process.

The structure adopted by the maintenance organization to conduct building services can be categorized as: centralized, de-centralized or area organized, functional organization, or any variation of these (Howard, 1984, sec. III, pp. 22-26): Centralized structures rely on one central location for receiving and dispatching maintenance crews to conduct the requisite services. In decentralized organizations or area-organized structures, the physical plant is divided in different geographic zones, each assigned to a maintenance team. Functional organizations tend to form groups divided by type of maintenance activities. However, there are no clear categories and facilities management firms often adapt the features of one or more kinds of structure to suit the organization.

The adoption of one form or the other significantly impacts performance feedback; the manner in which feedback is achieved and the level of feed back information. For example, in an area-organized structure, feedback of performance information occurs at a closer level. Maintenance teams have a high sense of familiarity with their buildings and thus symptoms and trends are easily identifiable. Centralized forms attempt to institutionalize the feedback process, by using a central control location for collecting performance information. However, in this process, the level of building performance information amongst maintenance units is reduced.

The potential benefits derived from applying more sophisticated management and planning techniques for building operations have off-shooted from the growing awareness of social and economic importance of maintenance in recent years. Most modern facilities management organization have some sort of "message-transfer structure" (Chessman, 1979, p. 125) - a system by which maintenance and repair information is received, recorded, and transmitted to the concerned units in-charge of these activities. These systems may be informal, based on verbal exchange of information or more sophisticated with computerized maintenance management systems. The basic objective, in both cases, is to allow for better planning, and management of building services, at the same time optimizing resources—labor, equipment, and materials—employed in the building process.

More sophisticated maintenance information systems are designed for achieving better management control of planning, scheduling, quality of work, labor productivity, and costs. Two major functions that exist in these systems are maintenance management and maintenance expenditure control. These also include a wide variety of supporting functions; work request systems; performance measures and control; work sampling techniques; and maintenance cost accounting systems (McGough & Gojdics, 1984, sec. III, pp. 45-46). The importance of these information systems, in the context of this study, is that they provide the required structure for storage, retrieval and processing of relevant information needed for analysis.

3.3 THE ELEMENTS OF THE SQC MODEL

The purpose of this model is to develop a framework for performance control by systematic feedback of information generated from building operations activities of maintenance and repair. The model is applied in two stages of the model. The first part outlines the process for prioritizing the most critical parts of the building inventory whose performance needs to be controlled. The second part outlines the actual process of performance control using on-going operations information in conjunction with historic information. Figure 3.3 shows a graphic representation of this performance management model.

3.4 INFORMATION

The basis of statistical analysis is hard data generated through the building operations activities. Historic data is required, both defining management priority areas and for establishing performance indicators. Data generated from current processes is used to find out the state of the process at any given time.

Data generated through operations activities such as M&R has the following characteristics (Anthony, 1965, p. 78):

a. It is often expressed in non-monetary term, such as man-hours, number of complaints, descriptive data, etc.

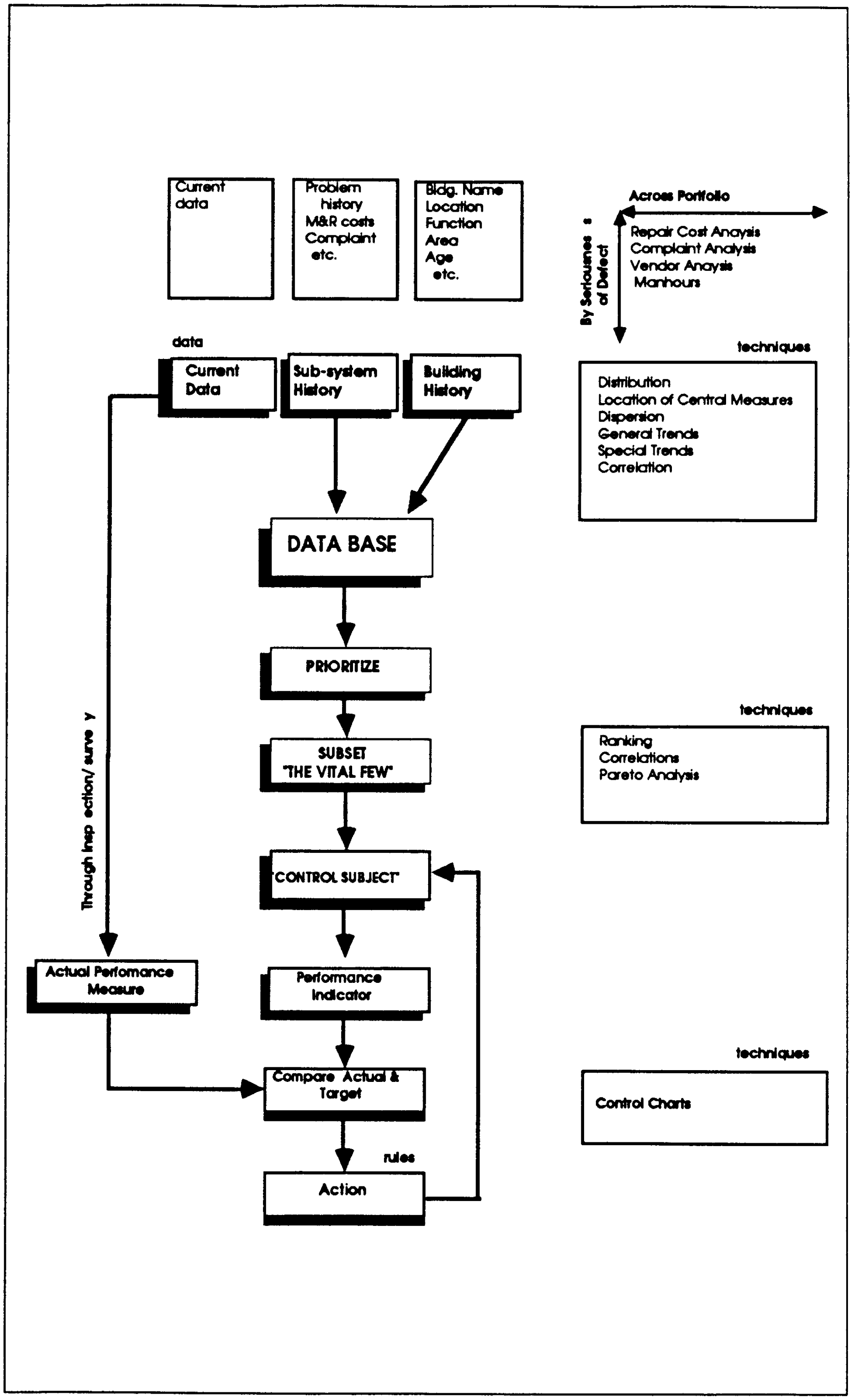


Figure 3.3: Building Performance Management Model

b. It is in real time, for example, many maintenance activities are finished by the time the payment of invoices are sanctioned.

c. It is activities-oriented and related to individual events or tasks.

The utilization of operations information is one of the most important features of this model. The use of SQC is stimulated by the requirement for evaluating the state of the process at any given time. Thus, to keep the performance of the component/ sub-systems/ building under statistical control, building managers needs to intercept variation in building performance before it occurs.

The database required for the model can be categorized in three groups:

a. Building history: eg. building size, age, location, function, components inventory, vendor, contractors, etc.

b. History of the control subject: eg. frequency of repair and subsequent cost, cost on different components, etc.

c. Detailed measurement of performance characteristics (collected for on-going processes).

3.4.1 DATA VARIABILITY IN HISTORIC DATA

The conceptual framework of the SQC model would depend to a certain extent upon the quality of input data. Skinner & Kroll (1982, pp.53-56) have pointed out the variability in historic data collected for maintenance costs. Ashworth & Au-Yeung (1987) have also discussed the inherent problems associated with the collection and analysis of historical maintenance cost data. They point out that the sample set required for statistical purposes in order to analyze trends can be represented by the zone of intersection between data-completeness, data availability, and data comparability. However, most maintenance organizations rarely store data for more that five years (ibid, p.142), and thus this sample set is not available with the current data recording and storing procedures.

The problems pointed out for cost data by Ashworth & Au-Yeung (1987, p. 141-143), suggest that the situation is even more difficult for data types that are non-monetary in nature. The motivation for storing cost data has primarily to do with the pre-occupation of the management with financial accountability and financial controllability. (ibid, p. 143) The author's investigation into the Physical Plant Department at MIT reveals that substantive operations information is not easily available for the period before 1984. At the same time, data required for statistical processing is needed over a long period of time, since many buildings systems have a relatively long life cycle and thus "live slowly".

The use of operations information for the SQC model brings to the forefront, the problem of data variability. Variability is a characteristics of data handled by statistical methods and is an expression of the difference between the items being studied. (Chessman, 1979, p. 129) Variability in M&R data arises due to three sets of factors; physical differences in the buildings, such as age, location, condition of the buildings, frequency of use, density of use; data collection procedures, dependent upon the skills of the operatives; and management policies (Ashworth & Au-Yeung, 1987, pp. 143-144). The necessity to study variability in historic or past data — its sources and characteristics — arises from the need to improve data collection practices, and consequently for improving the model itself. The first part of the model uses part information extensively, and thus variability of data arising out of data collection procedures needs to be considered.

Within the two major categories of building operations works, there are further sub-categories. Repair works may be categorized as major or minor; maintenance works may be defined in other sub-groups. These categories are too broadly defined barely indicative of the kind of work done and more often than not, these are not consistently applied. Data are recorded with the aim of maintaining cost accountability rather than with a view for future use.

Secondly, past maintenance data show that there is little way of judging the extent of work performed on a job (See Chapter Five). Most maintenance management systems have a provision for reporting-back the status of completed works, where descriptive status of the job is logged by the technician in charge of the job. Such types of information especially after a long period of time is vague and highly interpretive. Cost is the only indicative record of the extent of work done.

Thirdly, identification procedures for the type of jobs are dependent to a large extend on the skills of the technician and supervisor. Knowledge about distinction between various causes of of failure, such as bad design, detailing, fatigue, misuse or vandalism is rarely ascertained. (ibid, pp. 145-146)

Fourthly, non-identical replacement is a common feature in buildings whereby old materials, components, are often replaced by new items on the basis of cost, performance and other quality features many times over the lifecycle of the sub-systems. (ibid, p. 145)

3.4.2 COMPLAINTS AS THE BASIS FOR PRIORITIZING

Prioritizing occurs at different stages of the model. The objective at each stage is to rank the building components in some fashion such that critical building components may be identified. One measure by which priority may be established is by ranking the relative proportion of complaints received over a period of time, for a building/ sub-system/ component. This methodology implies that a direct relationship exists between performance and complaints. Figure 3.4 shows the the conceptual relationship between building performance, user and management .

"Complaints" as used in the context of this thesis is an assertion of performance quality deficiency. (Juran & Peach, 1974, sec. 15, p. 2) Complaints also refers to any information that sets into motions various activities of building operations; these may originate from the users or from the maintenance crews. Associated with every complaint reported, there is some degree of dissatisfaction on the part of the user, and an impact of cost on the part of the facilities management. Most modern maintenance

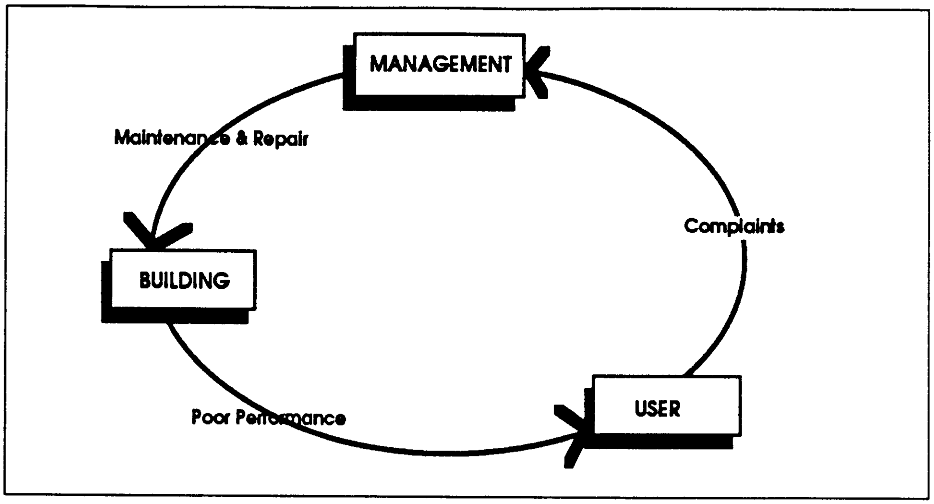


Figure 3.4: Building Performance ,Users and Management

organizations have work-request systems, whereby complaints can be received, transmitted and acted upon. These provide the required database for developing a systematic approach for delineating priority areas. Complaints analysis is an established methodology for assessing field performances of manufacturing products and feedback for further product improvement. The steps involved in complaint analysis are given below:

a. Recording complaints
b. Assigning priority.
c. Routing complaints to the best qualified department.
d Follow-up analysis.
e. Analyzing complaints over a period of time.
f. Management action.

This systematic approach for post-operations evaluation of complaints received during the building life cycle is not undertaken for performance analysis. At present, complaints are used simply to secure and locate knowledge of future maintenance and repair works.

Figure 3.5 shows the conceptual basis of using complaints for establishing priority and for comparison at different levels of the portfolio: At a higher level it would be used to aid management to compare performances of

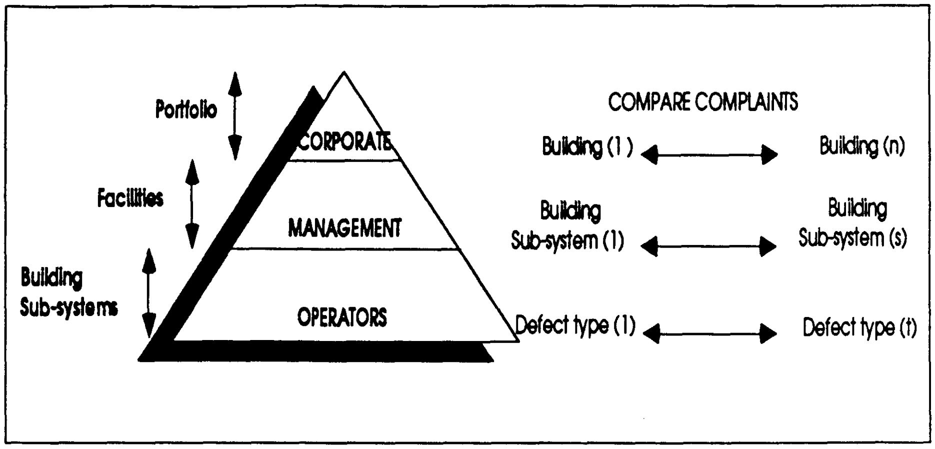


Figure 3.5: Complaints as Basis for Establishing Priority

different buildings/ facilities across the portfolio level. At another level, it can be utilized to identify the major items of the building inventory. At yet another level, it may to be used to rank the major kinds of defects.in a particular sub-system/ component.

The importance of using complaints as an index for performance, is that users are able to identify the immediate changes in the conditions of the environment they work in. As Magee (1988, p. 138) points out: "The users represent hundreds of eyes and ears that can alert the maintenance staff to deficiencies that encumber the ability of the facility to perform its intended function." Complaints as performance index is also related to two issues previously discussed in this thesis. The first is the association of quality of performance with the perception of the user. The second relates to the concern for facilities management organizations to provide services in the best manner. This is of particular concern with real properties that are revenue generating.

The limitations in this approach, nevertheless is that only certain types of performances characteristics are reported by the users. Thus, complaints as the basis for prioritizing performance is only valid for these characteristics. In other cases, it may be valid for maintenance organization to use another method for prioritizing, for instance cost of M&R could be used in place of complaints. Figure 3.6 shows the types of performance characteristics reported by the user and maintenance staff.

Another disadvantage with complaints is that many quality deficiencies are not reported by the users. The principle reasons behind this may be that: firstly, users perceive these deficiencies as unimportant. This implies that the probability that small defects go unnoticed is relatively high. Secondly, performance deficiency in areas which are not the immediate physical environment of the users or spaces with multiple users such as public spaces, service areas, circulation area, mechanical rooms, are often ignored by users. Thirdly, complaint are also unreported due to lack of technical knowledge on the part of the user, for example non-performance of mechanical equipments is largely unreported. In some cases, performance may be reported for these items in other forms such as, unusual noise, unusual odor, etc. Maintenance organizations typically evolve various methods whereby poor performance in buildings can be noted prior to actual failure. These include feedback from maintenance crews, facilities inspections and preventive maintenance programs.

Figure 3.6 : Types of Complaints Reported
Source : Magee, Gregory, "Facilities Maintenence Management", 1988, pp. 141-143

USER REPORTED	MAINTENANCE WORKS REPORTED
Specific Work Environment	**Discrepencies noted during PM Works**
Lack of Air conditioning/ heat Lack of Heating Malfunctioning Electrical Circuits Lack of Janitorial Services Safety discrepancy Unusual noise, odor	Required checks Observations on service equipment Observation on other equipment in the same Area
General Facilities Environment	**Casually noted discrepancies**
Malfunctioning elevators Malfunctioning plumbing Malfunctioning Doors, windows locks General Cleanliness	Similar to user noted problems but but concentrated within the workers trade specialty Items reported by users directly to work in lieu of work cente

3.4.3 CONTROL SUBJECT AND PERFORMANCE MEASUREMENT

Two initial decisions are to be taken: deciding the the control subject and choosing the appropriate measures for these control subjects. Hashimoto (1979, p. 33) states that statistical evaluation for quality control should be aimed at materials, methods, design specifications and other factors affecting quality. In the context of choosing control subjects, Juran (1974) points out that: "At a technological level, there are enormous numbers of control subjects: quality characteristics of the component, process, unit, subsystem, system; elements of documentation; myriads of measurements."

This model uses two criteria for selection of the control subject; firstly, management priority areas adjudged by the relative impact of the performance characteristics in the overall portfolio or facility; and secondly, the quality and amount of information available at any given time.for statistical purposes.

After the control subject is chosen, performance is quantified by choosing appropriate performance indicators. What constitutes a valid measure of performance, i.e. what are the parameters that can be used to quantify performance or non-performance of building sub-systems? Studies using statistical techniques for performance assessment have used the following kinds of control subject:

a. Maintenance & repair costs is the most common measure of performance. Skinner & Kroll (1982) have used cost of the maintenance jobs in residential buildings collected over a period of years for assessing maintenance performance and using it as feedback.

b Environment subjects where performance for assessed by the relative deviation from the standards specified initially. For example, Ventre & Ghare (1987) have used to assess performance of various environmental characteristics in office buildings such as acoustics, relative humidity, illumination, thermal comfort, indoor air quality. Performance is measured by developing a quality index corresponding to the above control subjects.

APPLICATION	CONTROL SUBJECT	PERFORMANCE INDICATORS
MECHNICAL & ELECTRICAL SUBSYSTEMS	HVAC Electrical Elevators	Mean time to repair Cost per repair call Mean time between repair calls
INTERIOR ENVIRONMENT	Thermal comfort Air Quality	No: of Hot & Cold Complaints per day
BUILDING COMPONENT	Roofing Doors Windows False Ceiling	Cost /repair Complaints/unit time No: of defects to total inspected
BUILDING SERVICES	Janitorial Service Vendor service	Response Ratio of maintenance hours to operating hours

Figure 3.7: Performance Control Subjects and Performance Indicators

Figure 3.7 shows the potential control subjects and the corresponding performance measurements. The four groups of control subjects are identified for performance control These groups, given below, can be suitably modified according to the size, management and organizational needs, and budgetary criteria of an individual facility:

MECHANICAL SYSTEMS &EQUIPMENT: The most direct application of SQC is for controlling performances of various mechanical systems used in building. Elevators is an elementary example of such kind.

INTERIOR ENVIRONMENT: Performance can be monitored for thermal comfort (complaint received are for hot or cold calls), air quality (complaints received are for lack of ventilation.)

BUILDING COMPONENTS: Building component defects are relatively easy to count. for example, doors (complaints are received for jammed doors, malfunctioning hardware); roof (typical complaints are roof leaks), plumbing (complaints received are for drainage, fixture leaks , clogged toilets, etc.); ceiling (falling tiles, lack of insulation).

BUILDING SERVICE: The application of SQC is directed at improving services provided by the facilities management organization as a whole. Performance measures would include repeat calls, mean time to response.

3.4.4 PERFORMANCE INDICATOR

Performance Indicators are target standards against which actual performance measurements are compared. Identification of target standards is one of the key decision-making functions of the maintenance organization. In most cases, there is a range of acceptability, the lower limit is set by the probability of failure and consequential loss to the user/ owner, while the upper ones is set by the cost of achieving it. (Lee, 1976, p. 30-31) Hashimoto (1986, p. 37) describes three target standards against which actual quality can be compared. The first quality level is set by the regulatory laws and standards; this is the minimum quality level. The second is set by management policies; this is usually based on past performance records. Lastly, quality level set by reviewing technical capabilities of the organization; this is typically used by firms to improve quality of their products for competitive purposes in the market.

In cases where the maintenance organization has no precedence for performance control, target standards can be established by the second method stated above using historical data for setting quality limits. Control charts "with no standards given", described later in this chapter may also be used to set target standards.

The performance indicators, albeit are not static. They may change due to two factors: firstly, due to a "secular variations" or trends. The change in performance level occurs most prominently in weather dependent performance characteristics. Performance indicators may change from season to season. Secondly, subsequent improvement in the quality of performance characteristics may lead to situation where the organization needs to re-instate the target standards.

3.5 TECHNIQUES

The word "Statistics' has two connotations: In the singular mode, is a body of theory and methods concerned with collection, processing, analysis and interpretation of data. In the plural mode, statistics are measurements or number of mass phenomenon, symmetrically arranged so that they signify their relationship. (Chessman, 1979, p. 129) There is no attempt to go through the basics of statisticalbut instead to focus on the use of statistical techniques for improving performance behavior.

Statistics is used to analyze data that exist at a particular point of time, a series of successive observations measured over a period of time, or to predict future observations. Correspondingly, three types of analysis are undertaken in the realm of SQC. The first uses past data to theorize about various performance characteristics. The second uses current process data for performance control. Lastly, future performance is predicted by means of experimentations and other advanced statistical methods. Figure 3.8 shows the various techniques available to the management. The discussion of the thesis is, however limited to the first two groups of tools.

Figure 3.8: The Kit of Statistical Techniques
Adapted from " What is Quality Control", Ishikawa & Lu, 1985, pp. 198-199

ELEMENTARY	INTERMEDIATE	ADVANCED
Pareto charts Cause - Effect diagrams Satification Check sheet Histogram Scatter diagram Control charts	Theory of sampling survey Statistical sampling inspection Statistical estimates & tests Methods of design of experiments	Advanced methods of design & experimentation Multivariate analysis Methods of operations research
TOP, MIDDLE & LOWER MANAGEMENT	MIDDLE & TOP MANAGEMENT	SELECTED MIDDLE & TOP MANAGEMENT

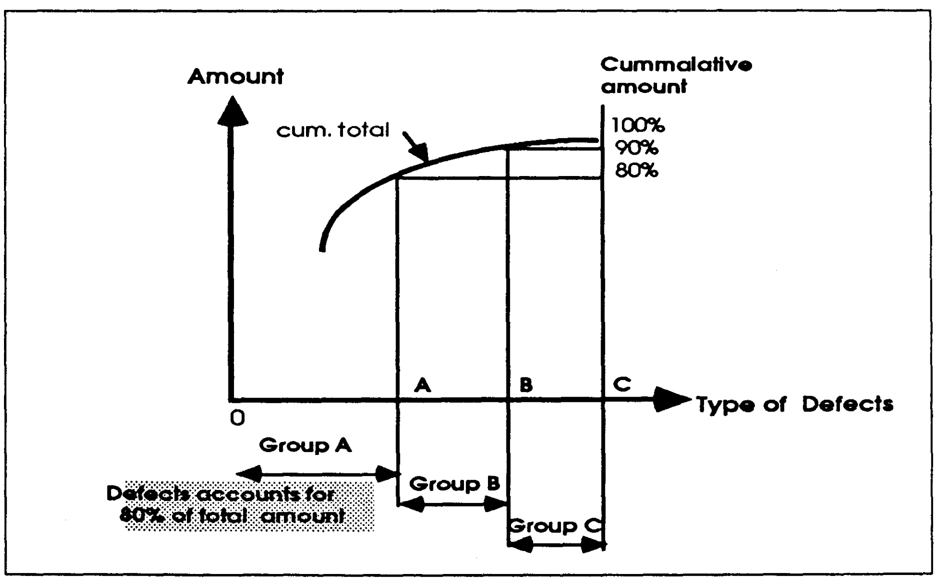
3.5.1 STAGE I: USING PAST DATA

This analysis comes at an early stage of the model because it is independent of current process and/ or any additional tasks of any experimentation. The tools used focus primarily on two analysis. First for establishing qualitative relationships between the defects and second relating percentage defective to some theory of causation such as design, types of materials, methods and practice. Both analysis can be undertaken using a variety of statistical tools such as: ranking, Pareto analysis, correlations, and matrixes.

3.5.1a. Pareto Analysis

The conceptual basis of Pareto analysis is that the bulk of the failure to perform is due to a small number of critical items. This phenomenon of the "vital few and the trivial many" was first observed in the field of economics in studying the extend of inequality or non-uniformity of distribution of wealth: Vilfredo Pareto, observed and applied it to advance the theory of "logarithmic value of law of income distribution." M. O. Lorenz, later developed a cumulative curve to depict the distribution graphically. (Juran, 1974, sec.2, pp. 16-17)

Figure 3.9: Pareto Analysis
Source : Hashimoto,Yoshitsugu, "Improving Productivity in Construction Through QC and IE", p. 11



The universality of this principle is that it can be applied to any local sphere of activity. The basic function of Pareto analysis is its use for identifying priority management area. For this study, the identification of management priority area is based on a statistical analysis of the complaints or failures being encountered. The aims of Pareto in the context of this thesis is: first, to detect "vital few" for further action and second, to design quality improvement programs. Economically, quality improvement programs can be justification for these "vital few" projects. (See Figure 3.9)

The type of data required for Pareto analysis is past data on M&R works, collected by building type, location, type of complaints, cause, complaints etc.

Other tools such as correlation, ranking and matrices may be used independently, or to substantiate Pareto analysis.

3.5.1b Trend Analysis

The second use of past maintenance records is for analysis of performance trends occurring in building components. Trends or 'secular variations" are paths taken up by a curve of a time series in absence of disturbing factors. Variation may occur due to number of factors; seasonal, associated with weather or other annual factors; cyclical, corresponding with trade cycles or planned cycles of operations; and unusual factors, such as catastrophes. (Chessman, 1979, p.143) Trend analysis is undertaken to answer important organizational issues for implementing the SQC model for performance control, for example, When should data collection for current operations take place? What are the leading indicators for performance variations? Does performance measure show seasonal variation? By how much does target standards vary with each seasonal period?

3.5.1 c Cause and Effect Diagram

Cause and effect diagram developed by Ishikawa is an important tool for problem identification and defining quality improvement programs. Cause

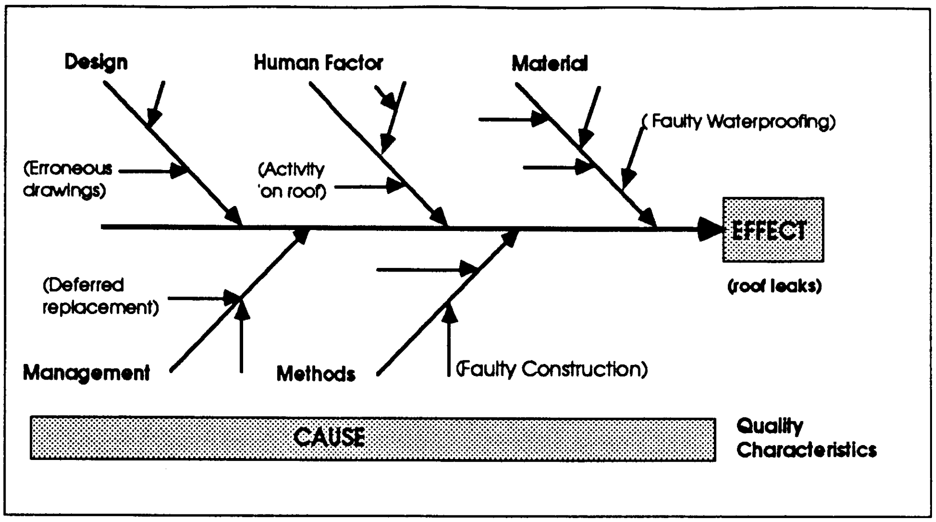


Figure 3.10 Cause-Effect Diagrams
Source : Hashimoto, Yogushitsugu, " Improving Productivity Through QC and IE", p. 15

-effect diagrams are a graphic representation of the various theories associated with a particular quality characteristics. This technique highlights various theories that can be subsequently put to test by using techniques such as Pareto, ranking or correlation and/ or studying current processes and/ or experimentation. In practice these theories are formulated during "brain-storming" sessions, where management and technical staff are collectively involved in bringing forth actual problems on the "shop floor". Figure 3.10 shows the cause and effect diagram typically used for analysis for problems of roof leaks.

3.5.2. STAGE II - USING CURRENT DATA FOR PERFORMANCE CONTROL

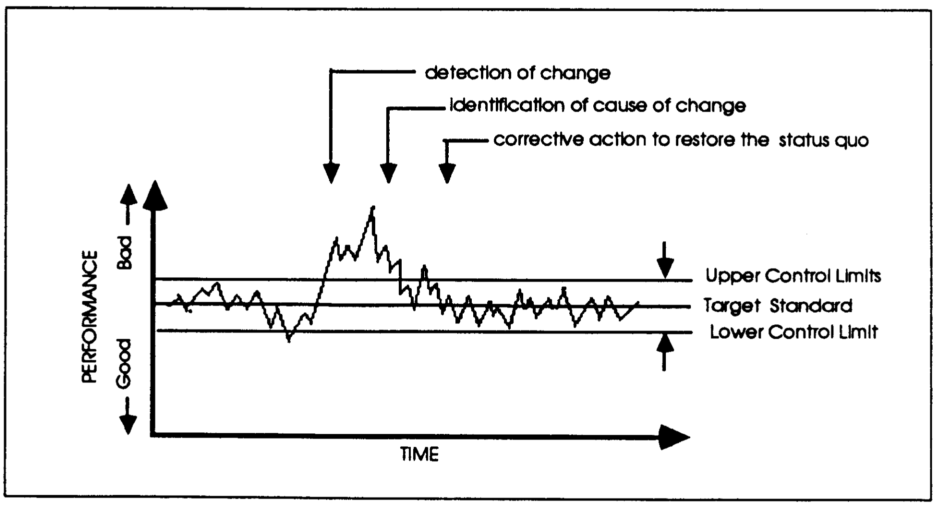
The second use of this model is for performance control. Performance control is aimed at controlling the critical quality characteristics of either, building, sub-system, component or the process itself. Performance control is achieved through the feed-back loop whereby, performance characteristics are measures, compared with target standards (performance indicators previously set by the management), and action based on this results.

3.5.2a Control Charts

A control charts is used to monitoring the "mean" performance quality. The aim of the control chart is to provides the management information about the state of the process, based on the small samples, taken periodically from the process. The control chart representation of the process performance data measured compared with the a range of acceptability, drawn as "control limits" on the chart. The process performance data also known as the "rational subgroup", is collected on a scientific basis, at regular intervals, from on-going building operations. (Gryna & Bicking, 1974, sec 23, p.2).Each subgroup provides a picture of what the state of the process is at that point of time. Figure 3.11 shows the conceptual basis of the control chart.

Variation is the measure which describes the extend to which data is dispersed around a central tendency. Process variation are of two kinds; the first is random, that is solely due to chance. Random variations are present in the process as a result of many elements that contribute equally and randomly to the variation. (Hradesky, 1988, p. 157) The second variation is assignable, i.e. due to a specific identifiable cause. Assignable causes usually result from abnormal variations caused by machines, types of material, skills employed for M &R, methods of works, or environmental factors. (ibid., p.157)

Figure 3.11: The Control Chart
Source Juran, J.M., 'Quality Control Handbook', 1974, sec. 2, p. 14



The ideal state of the process is when, only random variations are present because these represents the least amount of variation in performance quality. A process which is operating without assignable causes of variation is said to be under "statistical control." It should be pointed out at this stage that state of statistical control determines a condition where only random variation are present, it does not imply that the performance meets the target standards. (Gryna & Bicking, 1974, sec 23, p.4) Conversely, it can be said that a process not under statistical control may still be conforming to target standards. Action on such cases have much lower priority than those building sub-systems or systems whose quality of performance is not conforming.

Mathematically, the control chart is essentially a perpetual test of hypothesis. Thus, on a x-bar chart, each point tests the hypothesis that the mean is equal to the center line of the chart. If the point falls within the control limits, the hypothesis is accepted, otherwise it is rejected. Within three standard deviation limit, typically used in most control charts, the type I error is 0.0027. (ibid, sec 23, p.4)

The type of the control chart to be employed, depends directly on the choice of the measure of performance--whether variable or attribute. Indiscrete charts are used to plot variable data type, whereas discreet charts are used to plot attribute data type. The model for performance management described in this thesis emphasizes the use of discrete control charts, nevertheless, indiscrete control charts can also be employed for certain performance characteristics.

The measurement of data collected for performance control is through inspection of the sub-system or measuring the characteristics based on sampling techniques. Inspection, is a purposeful examination of the performance characteristics with the intent to collect performance data. This is one of the important organizational pre-conditions for performance control. This is required in order to intercept performance variations before complaints for these are received. As pointed out, earlier in the section, trend analysis and Pareto analysis are tools to aid this process by focussing on management priority area and providing leading indicators for this process, respectively.

The steps for setting up a control chart (ibid, sec 23, p.5-6) are discussed in the next few paragraphs using complaints as a performance indicator. This framework can also be used for other performance indicators.

STEP A: Identifying the "control subjects". This can be done by using Pareto analysis, ranking or any other tools, using past data, described earlier in this chapter. The control subjects are identified with the corresponding unit of measurements.

STEP B: Identifying the process variable that contribute to the quality of performance characteristics. This can be done by employing techniques such as cause-effect diagrams.

STEP C: Choosing characteristics which will provide the data required for diagnosis; these may be either attribute or variable. Attribute data (such as percentage defective) may need to be supplemented by the variables data for further study.

STEP D: Determining the earliest point at which inspection can be done in order to collect data. This can be easily determined by analysis trends of complaint by studying the period before there is a concentration of performance problems. (This is easily determined for weather dependents performance characteristics, such as roof leaks or lack of air conditioning or heating). In application where problems regularly occur, data collection must be an on-going process.

STEP E: Choosing the appropriate chart. Figure 3.12 shows the different types of charts that may be used in the process. There are two types of charts used depending on the type of performance measurement - discrete (using attribute data) and indiscrete(variable data).

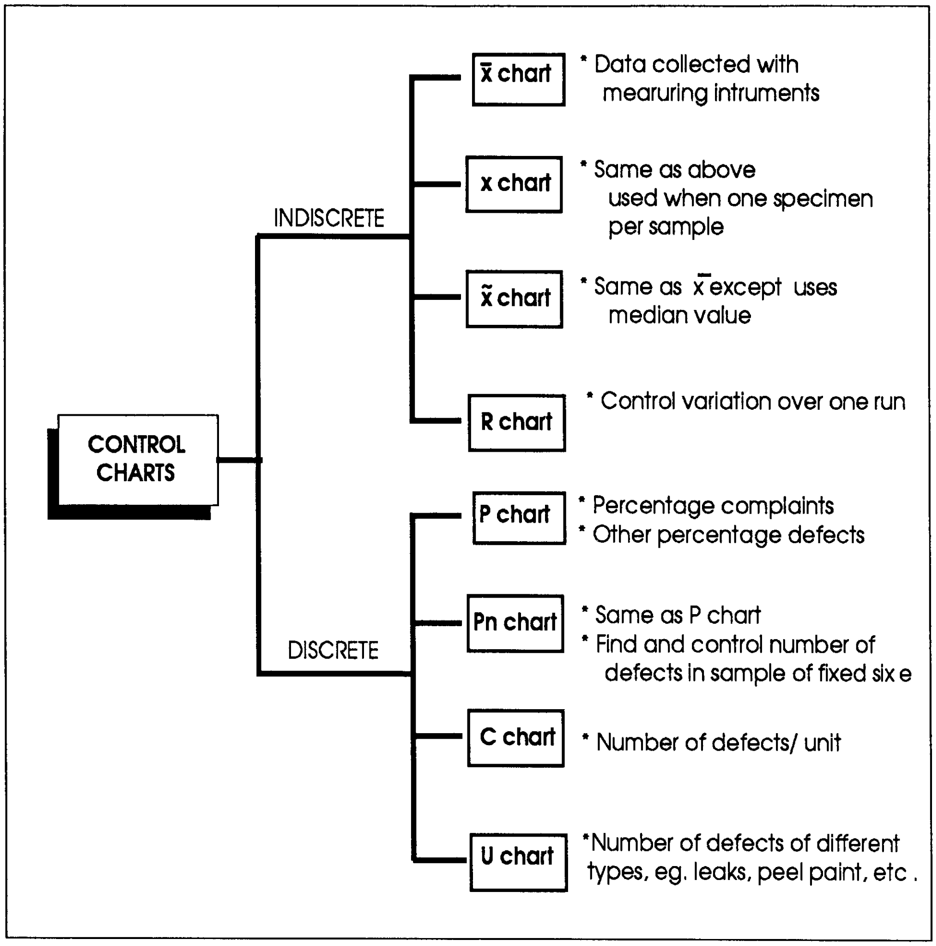


Figure 3.12: Types of Control Charts
Source : Hashimoto,Yoshitsugu, "Improving Productivity in Construction Through QC and IE", p. 11

STEP F Choosing the sample or the rational sub-group. The data chronologically plotted consists of a groups of units known as the rational sub-group. The rationale of choosing the sub-group is given by Grant and Leavenworth (cited in Juran, sec 23, p. 5-6): "Subgroups should be chosen in a way that appears likely to give a maximum chance for the measurements in each sub-group to be alike and the minimum chance for the sub group to be different from each other"

For performance control, the sample should be designed such that they represent appropriately the performance parameters of the universe. In keeping with the theme of this model, the universe represents the all the buildings within the portfolio.

The rational subgroup is based on selected items within the building portfolio which have different characteristics, for example, location, age, type of component, etc. It is beyond the scope of this study to define a sampling methodology; nevertheless is an important topic for future work in this field. One way of defining a rational subgroup could be using the sampling methodology developed by Ventre & Ghare (1987, pp. 1-8) for assessing performance of various workstations in an office building. Ventre & Ghare have defined a three step sampling process; the first step is the calculation of population parameter values or "identifiers". The second step involves deleted the identifiers if they are unimportant or combined if they are nearly the same as another characteristic and lastly, selection of the scheme to determine the subgroup combination, such that the sample set best represents the population.

STEP G: Collecting data. The collection and measurement of roofing data is generally carried out at specific points of the process. Data needs to be collected according to the relative seriousness of defects.

This is one of the important adaptation of SQC for performance control of building in-use. Classification of defects (particularly, in case of attribute data) is done according to the relative seriousness of performance variation. This approach is appropriate and valid; this is because one of the features of the building operations is the methodical ranking adopted by facilities organizations for the works to be undertaken to restore performance quality.

STEP H: Calculating the control limits. The use of ± 3 standard deviation as the warning or control limit, is based on the assumption that the sample means are normally distributed with the process mean (or the performance indicator). The control limits, graphically represented on the control chart provide information whether the process is under "statistical control" or not. As stated earlier, these control limits are dynamic, changing due to incremental improvement in performance or due to trends in performance characteristics. To identify the change in control limits, the "rule-of-seven" is applied, i.e. if at least seven points are above are below the control limit, then the control limits are to be re-instated. (Bland, 1985, p. 127)

STEP I: Interpretation of the control chart. The basic aim of the control chart is to identify the non-assignable variations. The graphical design of the control chart aids easy identification of the process being out of statistical control.

3.6 RULES

As quoted earlier in the section, SQC is "90% management and 10% statistics." Grant & Leavenworth (1972, pp. 13-14) point out that for an organization where SQC is to be applied, four levels of understanding of the subject are required. At the first level of understanding is the mathematics and uses as an analytical tool. At the second level is the general understanding of the principles underlying the various control charts, etc; this includes interpretation of results and so forth. The third level, requires a broad understanding of the broad objectives; this is needed at the higher level of management. A fourth level required use of one or more techniques on a rule-of thumb.

The first chapter introduced SQC as an analytical tool aimed for use at different levels of the portfolio, such as:

a. Building operators, for controlling quality of performance at the operations level.

b. Management level, for decisions for prioritizing building inventory.

c. Corporate level, for comparisons at the portfolio level for facility to facility by comparing various performance indicators.

The emphasis in this thesis has been the use of SQC by building operators and management use to aid decision-making on priority areas. Some organizational issues that relate to the use of SQC by building operators are discussed in the next few paragraphs.

3.6a For Operations Control

Most facilities management organizations rely on a central operations center for directing and responding to various in-coming complaints. SQC at the operation level is aimed at allowing these operations centers to close the feedback loop for a selected list of control subjects. The conditions for this is that operations center need a clear definition of the feedback process. Definition of the process involves the following; how the complaints are recorded, what standards are to be used, what deviation are be allow, and what action is to be taken in case of varion due to assignable cause.

The nature of issues to be considered for implementation, are essentially rule-based. These actions associated with SQC tools can be gradually incorporated in the standard operation procedures of the organizations. However, various issues of prioritization demand active involvement on the part of the management.

The outline of the process described above for performance management uses a variety of statistical techniques.These techniques though representative of SQC, however do not represent the total spectrum. There is a wide range of techniques; from simple techniques like the histogram, Pareto, cause-effect to more sophisticated experimentation that can be undertaken once organizational and management issues are resolved. These tools are based on the universal concepts of control and are equally applicable for performance management.

CHAPTER 4
CASE STUDY: BUILDING OPERATIONS AT MIT

4.1 INTRODUCTION

One objective of the thesis is to demonstate the applicability of the Statistical Quality Control (SQC) for performance management in real properties using the framework developed in the previous chapter. To realize this, a case study of the building operations process at MIT, is undertaken. The aim of the case study is to understand various issues brough forth by the model, from the point of view of an existing facility management organization. The first relates to the logistics of building operations itself and the second concerns various organizational issues for adoption of this model.

MIT's portfolio, presents an appropriate oppurtunity for testing the model described in the previous chapter. The MIT campus is a large physical plant; a collection of buildings, where day-to-day maintenance and repair activity is provided by several organizational units in many parallel processes. The goal of each of these agencies, is to supply services to the MIT community in the most effective and efficient manner. Physical Plant Department (PPD) is the largest of these organizations and most directly involved with the operations of the campus.

The reasons for choosing MIT as the case study and the subsequent methodology adopted for investigation have been discussed in the introductory chapter. However, PPD's role in performance management of MIT's real academic property need to be emphasized. MIT is one of the a leading research-based academic institute. Much of the academic and academic-related work done is dependent on the facilities on campus such as, laboratories, computer rooms, etc. The PPD has several organized procedures for conducting building operations in order to meet the high degree of performance and reliability needed to these specific areas and the campus as a whole. Consequently, building operation activities yields a great bulk of data, little of which is utilized for feedback and evaluation of performances of its facilities.

Chapter Four presents an extensive description of building operations process and the manner in which maintenance and repair activities are monitored by the PPD. The case study is undertaken in the following framework:

a) An overview of MIT's real property portfolio. This is included specifically, to set forth the context of the discussion.

b) The organization structure for conducting maintenance and repair activities; the functions performed by different units in the building operations process.

b) Existing information handling process; the procedure of collecting, manipulating and transmitting information of operations data, whatever its use is to be.

c) A review of the existing feed back and operations control.

Chapter Five uses the operations data collected for the roofing sub-system, as a demonstration of the the applicability of the principles of SQC for building performance control. The incentive for MIT's management to developed better tools for performance management tools is subsequently argued for in the concluding chapter.

4.2. THE SETTING

Since its establishment in 1865, the purpose of MIT (Massachusetts Institute of Technology) has been in "education and related research with relevance to the practical world as the guiding principle."(MIT, 1988a, p.8) The Institute is an independent, co-educational, privately endowed university having roughly five academic Schools- Architecture and Planning, Engineering, Humanities and Social Sciences, Management, and

Sciences -and the Whitaker College of Health, Science and Technology, and Management. Within these Schools and Colleges, there are some 21 academic departments as well as many inter-departmental laboratories, centers and divisions.

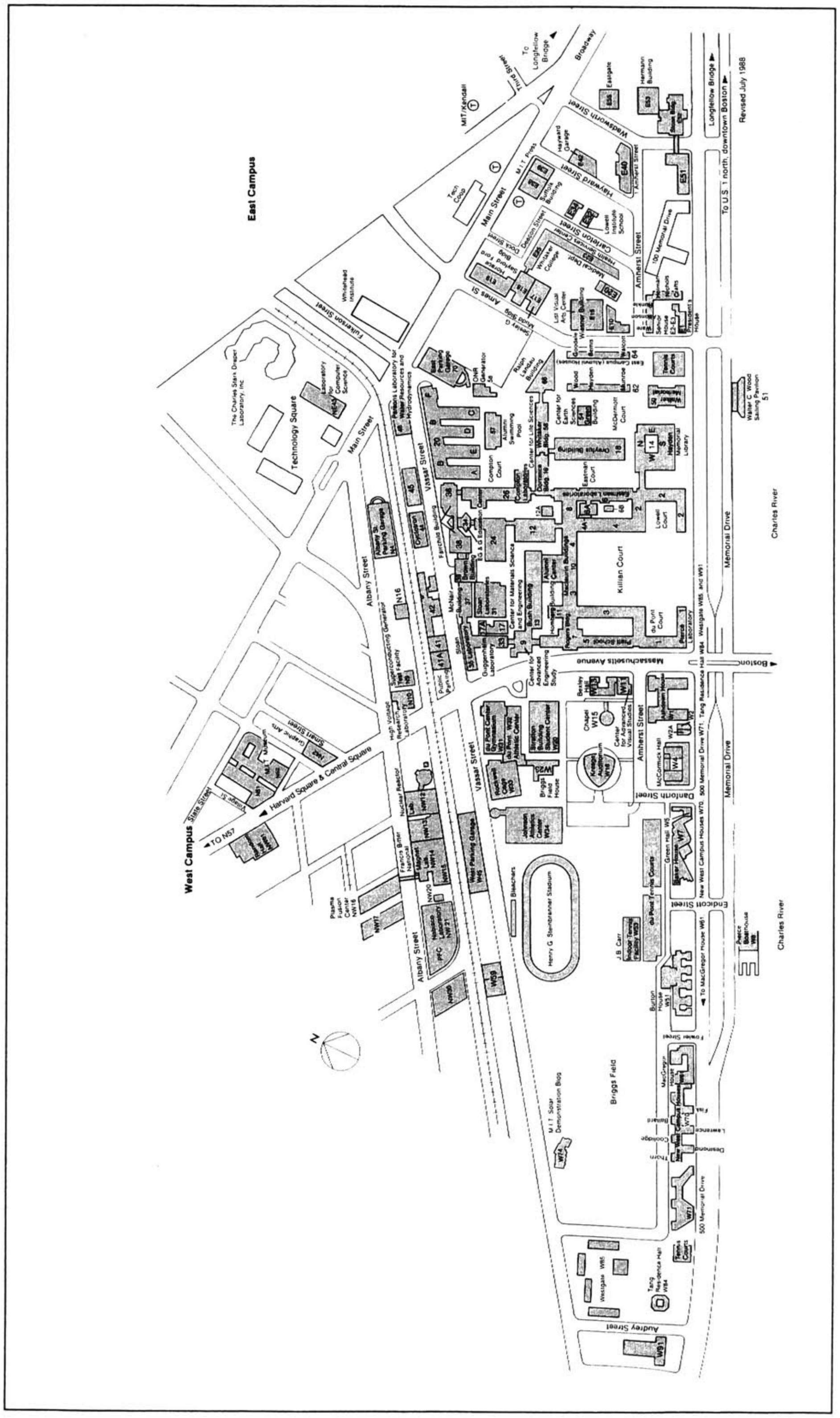
The MIT community embraces approximately 17,100 persons. Within this community there are; approximately 9,500 students, both graduate and undergraduate; the academic and research staff of just over 3,800 persons; and an administrative, support & service staff of 3,800 persons. (MIT, 1988b, p.2)

MIT's 146-acre campus is located along the Cambridge side of the River Charles facing the city of Boston. Figure 4.1 show the campus, divided roughly into three parts; the main, east, and the west campus. The majority of the academic facilities are housed on the main campus in a group of interconnecting buildings designed for easy communication and flexibility between various departments and Schools. The core of the main campus, known as the Macluarin building, was built in the early twentieth century. The main campus is the oldest stock of buildings on campus. The east campus contains the more recent additions to the campus, built mostly in the last decade such as the Whitaker College building, the Health Services Center, the Weisner building for Arts and Media Technology building. At the eastern end of the campus are the Sloan School of Management and an apartment building for married students. The west campus contains an extensive athletic plant, recreational facilities with dormitories, dining halls along Memorial Drive facing River Charles.

4.3 MIT'S REAL PROPERTY PORTFOLIO STRUCTURE

Figure 4.2 shows the structured collection of MIT's real property. The portfolio has two distinct categories, namely, academic and investment. The distinction rests heavily upon the primary utilization of the real property, i.e. whether the usage of the property is for academic purposes (hence tax-exempt) or for purposes of investment. As a result of this distinction, the operations and management of the two portfolio components falls under the jurisdiction of different offices.The two portfolio

Figure 4.1: MIT Campus



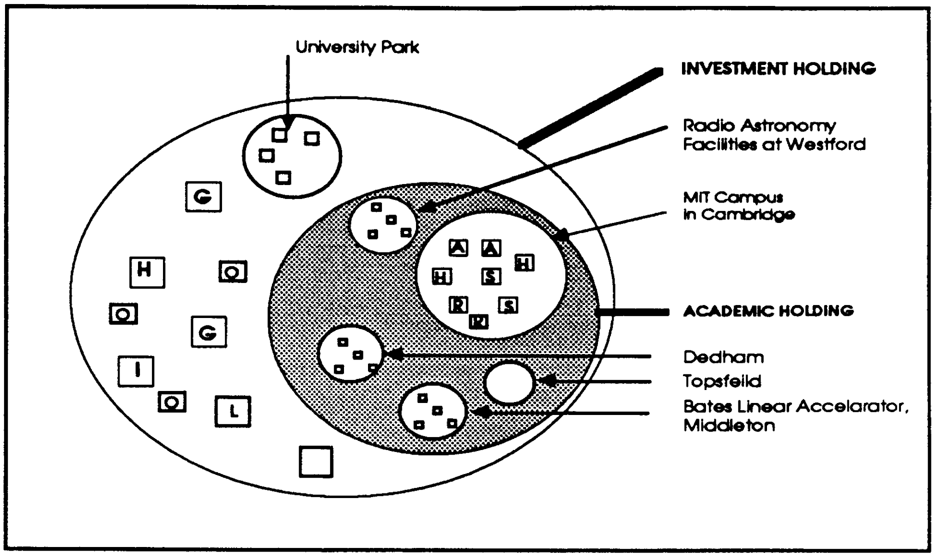


Figure 4.2: MIT's Real Property Portfolio Structure

categories have the following characteristics:

ACADEMIC HOLDINGS : The first category has all land and buildings used for academic or related purposes. MIT's holds about 5.3% of the city's total land area of 4,000 acres. Of these, 3.6% are in academic holdings in the 146 acre Cambridge campus. In 1988, the net usable square feet was approximately 9 million square feet in about 127 buildings. There are roughly four types of functions categorized as academic or academic related, concentrated in the same geographic area: (MIT, 1988b, p, 26)

a. Academic and Research: include all spaces assigned to academic and research departments (including research spaces), and interdisciplinary laboratories and centers. These include classrooms, laboratories, office spaces.

b. Support and Service: include spaces such as parking structures, circulation areas (stairs, lobby, corridor) and mechanical areas.

c. Housing and Food Service: includes all dormitories, apartments, and common dining areas, excluding all housing owned by independent living groups.

d. Administrative and Others: include all Institute spaces occupied primarily by; administrative departments; central services such as the Graphic Arts; auxiliary activities such as MIT Press; and spaces leased to non-MIT activities such as MIT Coop in the Student Center.

Apart from the property in Cambridge, the Institute owns 1,579 acres of land in academic holdings in other communities of Massachusetts. These areas are used mainly for accommodating other academic facilities. (MIT, 1988b, p. 22)

INVESTMENTS AND GIFTS: The second category comprises of real properties owned by MIT in investment holdings. About 30 properties are owned by MIT in Cambridge itself, mainly on the northern fringes of the Campus. Despite the primary objective of the Institute's use of real properties for academic and related facilities, the need for investment in Cambridge stems from a strategic viewpoint — for expansion and for purposes of controlling its campus boundary. The building inventory of properties in Cambridge, comprises mainly of commercial and industrial structures, along with some apartments buildings. Apart from investment holding, the Institute acquires real properties as gifts, many of which are international properties.

4.3.1 CHARACTERISTICS OF CHANGE

Over the years, MIT's real property portfolio has changed considerably. The characteristics of the change in the portfolio has been of two kinds:

Firstly, there is net growth of 3.4 million N.A.S.F.[1] in its academic holdings (tax exempt), since 1967. (ibid, p. 28) This is brought about by a correlative expansion in program offerings, improvement in the space standards and increase in the Institute's enrollment. The increase in academic and research spaces of over 700,000 square feet between 1967-1987 is attributed to acquisition of new facilities on campus, between the period 1972-77; Whitaker College, health sciences facilities, Medical Department facilities, and the Arts and Media Technology building. Academic spaces have also increased due to renovation of existing building structures for academic and research uses. The growth in academic areas has resulted in an increase in service and support areas by over 1 million square feet. The major decrease in area occurred in 1973, due to divestment of Draper Laboratories - an interdisciplinary laboratory, by approximately 350,000 square feet. (ibid, p. 28)

Secondly, there is a significant difference in the rate of growth in different functional spaces. The proportion between the different functional spaces to the total academic space is significantly different for academic and administrative spaces. While this may primarily be the result of the evolving academic requirements, the rapidly changing technology can be singled as an important attribute to the phenomenon. For example, during the period 1967-87, the School of Engineering and School of Science increased their total occupied space by 28% and 43% respectively. The laboratory area increased by merely 24% and decreased by 12% in the School of Science and School of Engineering respectively. In comparison, there was a significant increase in office spaces - 43% in the School of Science and 68% in the School of Engineering. Total support and service spaces increased by approximately 170%, implying that new academic facilities built in the last decade need greater amount of support spaces. (Pietroforte, 1989)

4.4 THE STRUCTURE FOR BUILDING OPERATIONS

The real property cycle can be broadly divided into three stages, beginning with unimproved land. The first stage includes, project conception, project evaluation, planning and design, and financing. The second stage is procurement and construction, and the final stage begins with the utilization and operation of the real property. (Bon, 1989, p. 16-17)

Within MIT's portfolio structure, two real property cycles occur simultaneously, each independent of the other for the majority of the cycle. Figure 4.3 shows the two property cycles- academic and investment and the departments within MIT associated at each stage. The responsibility for building operations is structured along the two portfolio components- academic and investment. While the Real Estate Office (REO) manages the operations of all properties in investment holding, the Physical Plant

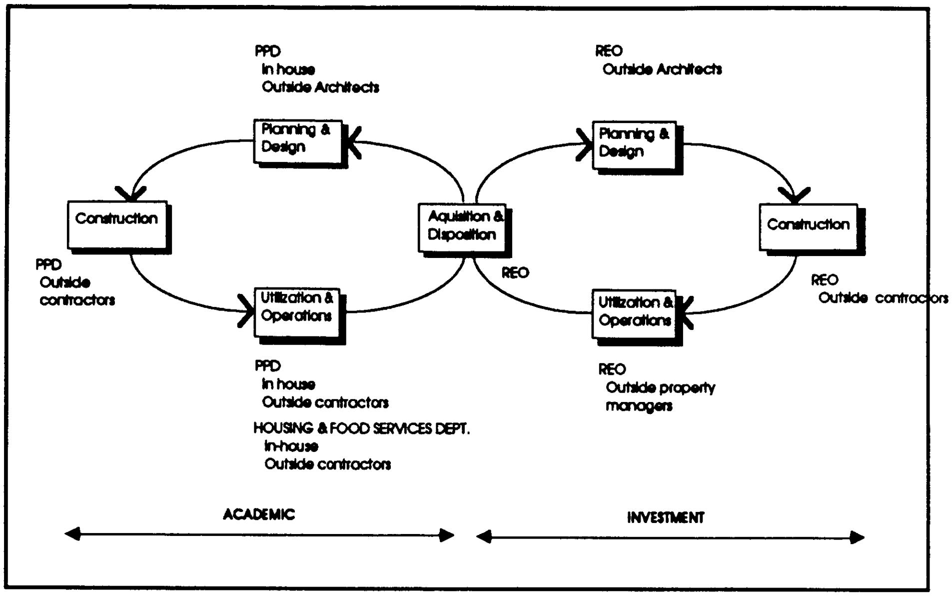


Figure 4.3: MIT's Real Property Cycle: Academic and Investment

Department and the Housing and Food Services Department are actively involved with the operations of the campus and housing services respectively. A fourth organization, the Office of Facilities Management Systems (OFMS) performs an associated task of space management and allied research in facilities management.

ROLE OF THE REAL ESTATE OFFICE: The primary mission of this office is to make investments in real properties such that there is a return of income to the endowment funds. This office, working under the Treasurer's office, acts as an independent real property agent for the Institute. It handles the centralized function of acquisition and disposition of real properties — whether academic or investment holding or received gifts.— for the Institution as a whole. Secondly, it oversees the operations and management of all non-academic investment properties, by either hiring outside property managers or by doing the job it in-house. Thirdly, it sometimes act as a developer in order to bring properties to Institute and market standards.

Since acquisition and disposition is a centralized function, the REO interacts with the PPD for a period of time of the real property cycle. The nature of interaction is that each organization seeks the services of the other, to handle work in their respective expertise. For example, PPD would ask REO to handle the sale of all revenue generating spaces, such as retail, contained in academic or related properties. Similarly, the REO consults with PPD while acquiring properties for academic use.

THE OFFICE OF FACILITIES MANAGEMENT: The OFMS is involved in "education, research and technology transfer" in the areas of facilities management. The OFMS has developed the computerized facilities management system, and since 1973, shared the technology with a consortium of users from academics, healthcare, corporate and government institutions. The fundamental application of INSITE (Institutional Space Inventory Technique) at MIT, has been for managing space and equipment inventory of the physical plant. Other uses of INSITE include indirect cost allocation, grant and project tracking and equipment depreciation. The INSITE Consortium was formed to encourage the ideas, data and experiences of facilities management and its members benefit from the ongoing educational and research activities in the team.

4.5 BUILDING OPERATIONS OF ACADEMIC PROPERTIES

4.5.1 INTRODUCTION TO THE PHYSICAL PLANT DEPARTMENT

The aim of the PPD is to keep, restore and improve every building (except academic housing) on campus, its services and surrounding to acceptable standard and sustain the utility and value of the facility. It performs assigned building services and support functions with optimum effectiveness and efficiency, yet with minimum interference with the primary mission of the institute — namely research and teaching. Apart from maintenance, the PPD also provides; design services on renovation jobs and new construction; utilities; and other related services.

The annual budget for the 1989 Fiscal Year (FY)[1] for the PPD was approximately $40 million. Of these, $ 13 million were fuel and energy costs. Other sources of funds for physical plant works include; the $1.4 million from the Maintenance & Repair Operations fund; $4-5 million from the Space Change funds; $60,000-$70,000 for the HVAC upgradation works (to be used only for the expansion of the mechanical systems); and other discretionary funds, if and when required. All major renovation and architectural projects are funded by the Capital funds.

4.5.2 ORGANIZATION STRUCTURE

There are four major categories for organization of the physical plant work and two supporting categories. Figure 4.4 shows the organization structure of the PPD. The structure is hierarchical with the director at the head, in-charge of various functional units. The functions performed by the major units in the PPD are given below:

ADMINISTRATION: The administrative offices manages the organizational arm that deals most directly with the clerical functions of the department. It is responsible for functions such as personnel records and typical secretarial duties. The personnel unit in this division, also assists the administration and coordination of two maintenance teams for the Athletics department and West Campus complex (includes the Students Center, Kresge auditorium, the MIT Chapel etc.).

BUSINESS OFFICE: This division manages the function of; budgeting; management of stockroom which provides Operations with access to frequently used materials, supplies and tools, inventory; and accounting. An independent Physical Plant purchasing agent operates within this unit and all materials requisition are handled by him providing a centralized, internal buying facility.

SYSTEMS MANAGER: Previously, under the administration division, this has recently become an independent division. It is actively involved in design and implementation of computerized data-processing and management information systems to aid the PPD in its functions.

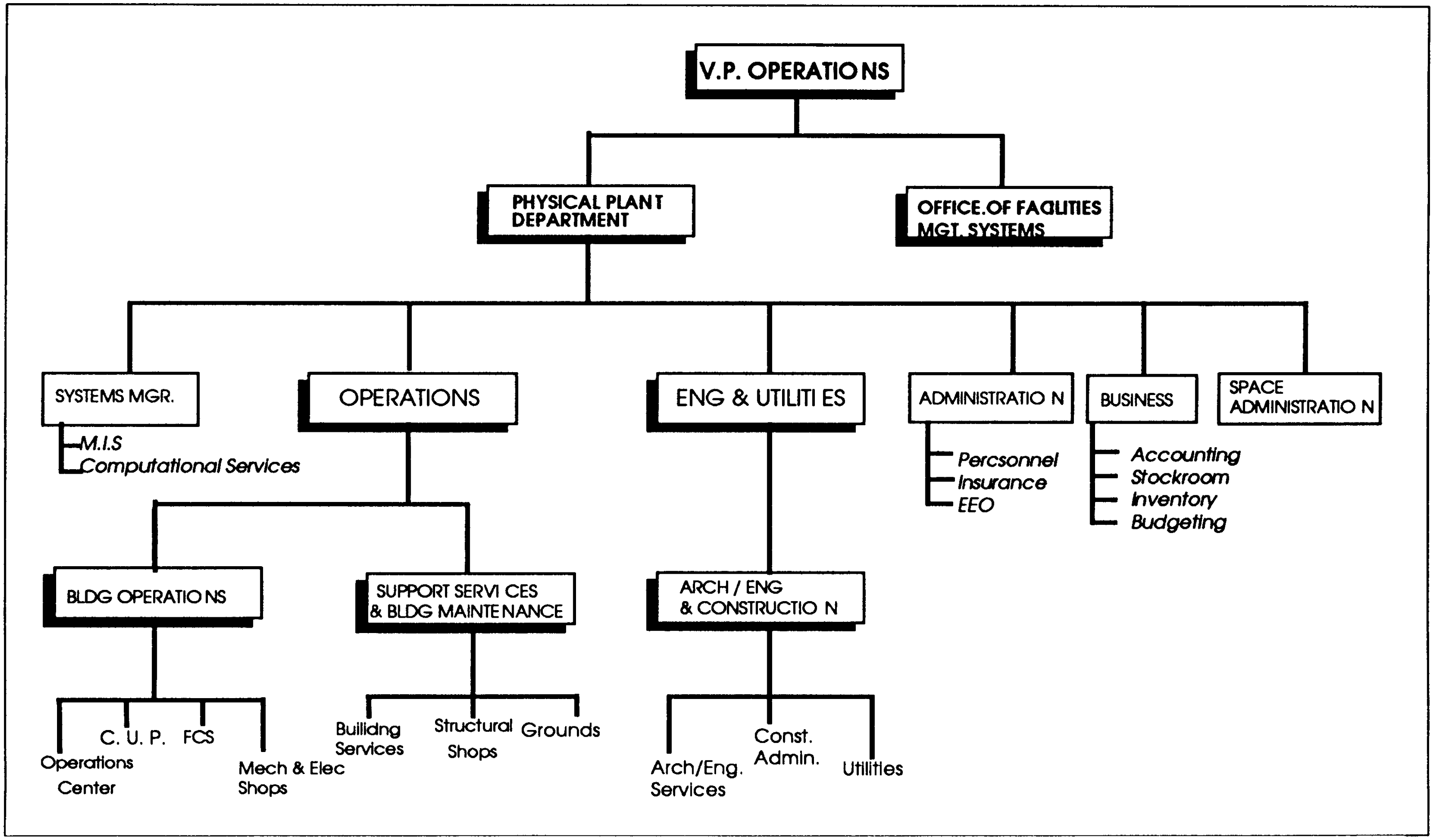


Figure 4.4: Organization Structure of Physical Plant Department

ARCHITECTURE/ ENGINEERING & CONSTRUCTION: This division under the Engineering and Utilities provides architectural/ engineering and construction administration services, for all major renovation and new construction for the academic portfolio. Outside architects and contractors are commonly hired for their services. It is the responsibility of the Superintendent to ensure that the architectural and engineering drawings are in compliance with the MIT design standard and specifications. Contractors' bids are evaluated, negotiated and awarded by this office. The project managers monitor and coordinate work under progress, with other Institute departments.

Apart from rendering architectural and engineering services, this division also oversees utilities systems assisted by the Central Utilities Plant manager in the Building Operations division. The Central Utilities Plant purchases fuel and electrical power in bulk and distributes it throughout the campus. The aim of this unit is to achieve the maximum efficiency in energy conservation. Economy is achieved by providing in-house heating and cooling facilities as well as transformers and distribution systems for electricity. (Leler, 1975, p. 12)

BUILDING OPERATIONS: The building operations division encompasses the activities of; the Mechanical and Electrical shops including supervision of preventive maintenance programs; the Operations Center; the Facilities Control System; and the Central Utilities Plant.

Mechanical and Electrical shops supervise the preventive maintenance programs and are also responsible for over-seeing different sub-contacted works. The manager of mechanical operations co-ordinates the mechanical, plumbing, electrical, HVAC and fire/ water shops. Each shop is run by a foreman and employs about 40 mechanics, 16 fitters and 8 clerical workers

Operations Center is a central location and the heart of all building operations activities. The primary function of the operations center (OC) is to receives, records and communicates complaints or work requests from various sources throughout the campus, to the concerned functional unit within the PPD.

SUPPORT SERVICES AND BUILDING MAINTENANCE: Three types of activities are administered under this division. This division employs the largest number of personnel, as building operations works is characteristically labor intensive.

Building services include all housekeeping and janitorial services of all areas of the campus except housing: cleaning and maintaining the floor & wall surfaces, vacuuming and carpet cleaning, dusting and window cleaning, light bulb and tube replacement, set-up and special events, trash removal, etc. It also collects and distributes the inter-departmental mail throughout the Institute.

Ground services include landscape management and campus service such as maintenance of pavements, masonry repairs, sewers including all athletic facilities such as the swimming pool and ice rink, indoor and outdoor tracks, etc. Under the direction of the grounds manager, shuttle transportation for Physical Plant workers and their equipment is also provided.

Structural Shop has four shops under their charge; the carpenters shop, locksmith shop, paint shop and metal & glass shop. Each shop is supervised by a foreman who organizes responses to complaints and work orders. A substantial amount of services by the shops are undertaken for individual customers, as sales jobs outside the routine M&R work. Customers for these services are normally from within the MIT community. The popular works undertaken for "sales" jobs are painting of rooms, cabinet making, and other special requests.

4.5.3 ORGANIZATIONAL OPTIONS FOR MAINTENANCE MANAGEMENT

Building maintenance activities are more or less structured discipline of responding/directing relationships. Various organizational options are available with the Physical Plant Departments for structuring these relationships. These organization forms may be centralized, de-centralized or area organized, functional organization, or any variation of these. (Howard, 1987, sec. III, pp. 22-26)

Until 1979, the process of maintenance management at MIT, was dominantly area-organized, i.e. the Campus was divided into three geographical zones- the main, east and the west campus. Further, each area (groups of buildings) was assigned to individual teams of craftsmen. These teams were made up of mechanics, electricians and plumbers; often many of these were multi-skilled individuals who accomplished maintenance at various levels; preventive, corrective or renovations. What fostered in this approach was a relatively high sense of familiarity with buildings, systems and needs of clients within their assigned territory. Closer supervision and inspection was possible as were the advantages of faster response on minor repair works. The obvious disadvantages of this system was that diverse levels of maintenance existed within different areas and zones, due to the individual skills of the teams. Furthermore, there was duplication of equipment, tools and resources and consequently less efficient utilization of equipment and resources.

By 1979, reorganization of operations work in the PPD was forced by the decided shift from an area-organized to a centralized system. This shift was brought about by the implementation of the computerized system required to modernize and to keep pace with increasing operations activities, due to overall growth of the MIT's academic portfolio. This system allowed central planning, work control and co-ordination. Centralized structures for operations are in fact popular organizational forms for colleges and universities. The work control center which served as the administrative/ clerical/ operations interface under the administration division (Leler, 1975, pp. 13) was streamlined into the operations center under the building operations division. Subsequently, the operations of the Telecommunication division was removed from the PPD to form a separate department, as response to increased communication needs of the

Institute.

The reorganization resulted in some obvious changes within the PPD. Firstly, there was a reduction in the number of union employees from 625 persons to 450 persons. Secondly, there was an increase of technical personnel in the PPD. With the introduction of various computerized systems, there has been an appreciable increase of skilled workers in this area.

The advantages of a centralized system was evidently in the more efficient use of skills and resources. The system allows a greater source of experience and talent to draw on, efficient use of equipment and better use of emergency response personnel. Planning, scheduling and coordination of work is also more efficiently administered through the centralized system eliminating any overlap of activities. The major disadvantage of the centralized system is that there is a lesser degree of craftsman familiarity with the buildings/systems and facility details. There is also a lower awareness of level maintenance requirement and job assessment takes longer time.

Another distinct change in the PPD is that there is a reduction in the number of jobs performed in-house and increased utilization of outside services. There obvious reason for this is the increase in specialized services available — ready and inexpensive — within the building industry today. In addition to this, the relationship between labor and management have changed considerably over the years, particularly with development of unionized labor. The high cost of permanent labor has forced organizations to contract out a higher proportion of jobs, instead of maintaining a large permanent crew

4.6 BUILDING OPERATIONS: THE EXISTING SYSTEM

Building operations refers to the process of day-to-day provision of supports and service functions that contribute to the successful mission of the Institute. Building operations work at MIT is organized in two functional disciplines: The first area include operations of utility distribution systems, mechanical and electrical systems, and other support systems. The second area encompasses operations and management of maintenance and repair (M&R) activities. Continuity of operations in both the above area is an important requirement for the Institute, for serious loss - monetary, academic, safety may result due to malfunction in any of the buildings/ systems/ component.

Continuity in operations is ensured by establishing various forms of control systems devised for assuring that the process is carried out effectively and efficiently. Operations control focuses on individual tasks or transactions: scheduling and controlling of individual jobs through a shop and specific personnel action. (Anthony, 1965, pp. 67-68) Operation control is achieved within a set of well defined procedures and rules (such as the Standard Operating Procedures (SOP)) derived from strategic and management planning criteria. The SOP manual for the PPD outlines various building operations procedures. It includes; roles and responsibility of the management and staff; jurisdiction of work of different functional units; procedure for allocation of jobs; interfaces between the functional units; work procedures of the operations center; various PPD policies; MIT departmental policies, etc., all geared to enable smooth running of the department as a whole. Decision-making for operations is thus based on objectivity, for actions are to be followed by more or less, decision rules imposed upon by the management through the SOP. The data generated through the operations process is largely non-monetary, it is in real time, and relating to individual events. (ibid, pp. 76-78)

Building Operations Control at MIT is achieved through two practices:

a. By a system of the complaint management, in place at the PPD, and

b. By programmed control through a preventive and planned maintenance schedules.

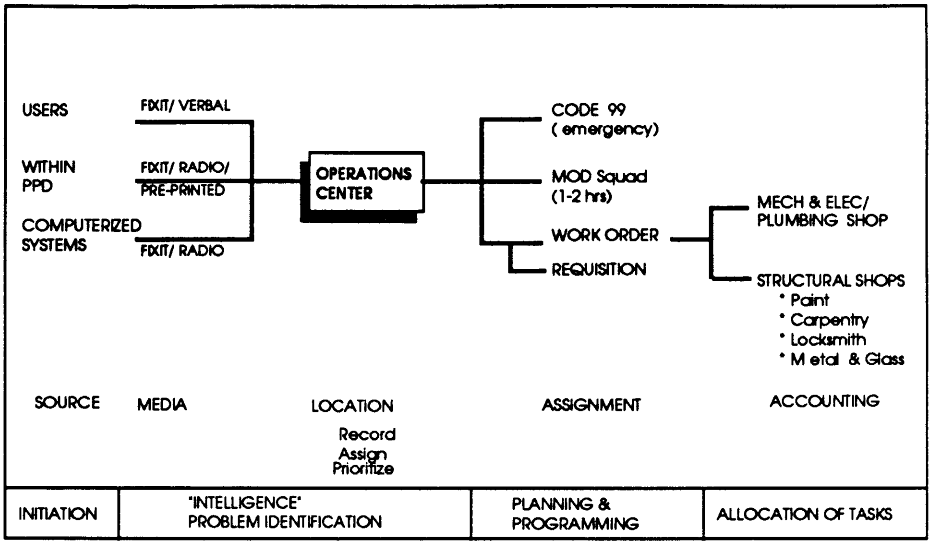


Figure 4.5: Complaint Management at MIT

4.6.1. COMPLAINT MANAGEMENT

Complaints can be defined as an assertion of quality deficiency. These are made by the users and associated with each compliant is some degree of dissatisfaction about the performance of the building. (Juran & Peach, 1974, sec. 15, p. 7) The preliminary action to be taken upon receiving a complaint is to ensure the restoration of service which is the source of dissatisfaction. Complaints as used in this thesis implies any information that sets in motion the process of building operations activity. Complaints are also referred as "trouble calls" or "work requests" in the organization.

To assist the function of complaint management, the present operations system relies upon the OC in the Building Operations division for providing the interfaces between the users of the facilities - who demand services and the job-shops - who supply services. Figure 4.5 shows a simple three-stage sequential process in which maintenance and repair complaints are received, recorded and assigned to individual service units. The process occurs through a computerized work request systems, whose purpose is to establish accurate information upon which assignments, work-orders and follow-up can be based.

In 1988 approximately 40,000 complaints (including repeat calls) were received by the PPD. The PPD relies heavily upon its users, via complaints, to provide information about prospective maintenance and repair works. The process of complaints management is described in the next few paragraphs.

STAGE I- Receiving & Recording Requests

The OC is in-charge of administering the work order system and controlling the work flow. The complaints/ work requests/ trouble calls are the most important mode by which building management can know of any malfunction in the facilities. The channels of communicating for requests are telephone calls (through "FIXIT", an Institute service available round the clock), written forms or verbal appeals. Whatever the source of these requests may be, the operator is required to obtain as much information as possible about the nature of work from the requestor. This information is used directly by the operator to prioritize the job and assign it to the appropriate service unit. Since January 1988, the OC has in place a computerized work request system and in-coming calls are logged on-line. The information recorded through this process is aimed at generating a work order and includes the following information: (See Exhibit 4A)

1) Location- Building number / Room number.
2) Exact location where the work is to occur.
3) Definition of the work
4) Person making the request / Phone number / Address
5) Date/ Time
6) Comments (as noted by the operators)

Typical sources of Work Requests

Complaints or work requests are generated from various part of the MIT community. These can be categorized, by source, into three groups:-

Users on-campus: This is the largest group of users placing complaints; students, faculty and administrative personnel. Request for maintenance and repair works are places mainly through the FIXIT phone line.

PPD Staff: Apart from the direct work requests, the PPD has evolved its own process of collecting information on prospective maintenance and repair work in the 127 buildings under its charge. The type of work

Exhibit 4A: Work Request Form

```
___   7-MAR-1989 10:59:39 _____________________________________________________
                                  ** ENTER TROUBLE CALLS **
===============================================================================
Caller:                                              +-------+---------+-----+-----------+
Ext:                Equip No:                        |Ref No |Date     |Time |Operator   |
+--------------------+                               |-------+---------+-----+-----------|
|Locations (Bldg/Rm)|                                |W146799| 7-mar-89|10:57|RCOATE     |
|--------------------|                               +-------+---------+-----+-----------+
|                    | More Info About
+--------------------+ Location:
Problem:



Comments:

Completion Confirmation Required?:          Caller Address:

Assign To: Mod Squad:       Log Only: Duplicate Request:
           Shop Name:                 Shutdown:
           Code 99:                   Other:
-------------------------------------------------------------------------------
_______________________________________________________________________________
```

reported is either new or additional work encounter by the job-shop mechanics and custodial staff while performing their routine work in or around the assigned area of work. The kinds of works reported by maintenance crews was discussed in chapter three.

The mechanical and electrical shop workers report new or additional repair work on mechanical, electrical or plumbing jobs. In most cases, the work is reported directly to the operations center, which in-turn treats it like a routine complaints. However, exception to this standard procedure is under two situation: in case of urgent work or in case of minor repair work. In both cases, work is reported after it has been completed. It needs to be pointed out that the decision to undertake the work lies with the mechanic on-job and subjected to his perception and experience.

The custodial staff reports on all work pertaining to the structural shops- such as the condition of fittings and fixtures, building envelop, etc. Collection procedure for such information involves filling out a short pre-printed form by each janitor on-duty. (See Exhibit 4B) This form is issued by the Support Services and Building Maintenance division, collected at the end of each working day and reported to the operations center. Additional work requests are also reported by the technical staff while on the preventive maintenance schedule.

What is suggested by this process is a form of area delineation, where the users on campus- students and staff actively report all complaints facilities directly used by them such as laboratories, research, office and administrative areas and the custodial and technical staff reports all prospective work in public & circulation spaces such as corridors, classrooms and lobby spaces.

Flagging from Computerized systems: The computerized system continually monitor various emergency alarms to detect malfunctions such as fire systems, HVAC systems, as well as interior environmental control systems, in sensitive areas are the third source of work.

Exhibit 4B: Pre-Printed form for Housekeeping

Date: ______________________ SHIFT: 1 2 3

BUILDING/ROOM NO. ______________________

NAME ______________________

REMARKS: ______________________

____

____

____

BROKEN GLASS: In Window - In Door - Other

DOOR CLOSERS: Broken - Will Not Work
(Type Door) - Wood - Metal - Glass

DOORS: Sticks - Sagging - Broken
(Type Door) - Wood - Metal - Glass

ELECTRICAL REPAIR: Switch - Wall Plug

FLOOR TILES: Loose - Missing

LEAKING: Faucet - Shower - Toilet -
Urinal - Pipe - Radiators

LIGHT REPLACEMENT: Bulb - Tube

LOCKS: Broken Key in Lock - Loose -
Hard to Lock - Hard to Unlock

PLASTER: Broken - Cracked - Loose

PLUGGED: Floor Drain - Sink - Soap -
Dispenser - Toilet - Urinal

REPAIR CLASSROOM: Chair - Chalkboard -
Desk - Lectern - Table

WATER FOUNTAIN: Leaking - Water is Warm -
Noisy Motor - No Water - Plugged

TOILET FIXTURES: Seat: Loose - Broken -
Tissue Holder: Loose - Broken - Missing

CARPETING: Needs Repair

WALL TO WALL: Yes - No

STAGE II- Stratification, Verification and Assignment

After receiving and recording the complaint, the second step in this process involves stratification of work requests i.e. assignment of priority for the work to be done. The assignment process works on two parallel concerns — first, on a "first-come-first served" basis in order to be fair to all users and facilities requirements and second, based on the nature of the work request, based upon a set of well-defined guidelines established by SOP manual. In this context, the SOP documents responsibility for the various actions to be undertaken in responses to routine calls and implementing the preventive maintenance system. Despite the SOP, it is the operators responsibility to adjudge the work request appropriately and assign priority to the job. Given the nature of this task, the PPD has routinely brought in technician from the job-shops who have multi-skill knowledge and experience to be able to allocate priority of tasks appropriately.

There are three classes of priority to which an in-coming request may be assigned, based on a defined priority. The stratification of work requests/ complaints into classes suggest the responsiveness (as measured in time) appropriated by the management for the different types of requests.

Priority 1: The highest priority is given to works that are hazardous to life, health, and property.These include all works needed; to provide or restore adequate security to the facility; to eliminate hazards to life or health; or to protected valuable property, are assigned to the emergency unit popularly known as Code 99. The responsiveness for such jobs range from immediate to thirty minutes. The kinds of work that are assigned to this class range from, fire responses, alarms from animal laboratories to broken locks of laboratories having expensive equipment.

Priority 2: All works that are urgent but not emergencies are assigned to the maintenance-on-demand (MOD) team. These jobs require to be responded between 1-2 hrs. In most cases, the MOD squad performs a preliminary inspection of the situation and reports it to the OC, who in-turn issues a work orders for it. However, it performs all urgent work that

Exhibit 4C: Work Order

```
                MIT PHYSICAL PLANT WORK ORDER        WO NUMBER: W108671-0

      Status: CODE 99                               Date Issued: 21-nov-1988
Requested By: NIGHT WATCHMAN                      Date Required: ASAP
     Address:                                    Requisition No:
         Ext: *

Problem/Task: GOODDALE 212, LOCK IS BROKEN


Comments:

   Equip No:
Description:

 Project No:                  Project Coordinator:
Description:

Locations:   W61-


More Info About Location:

          Lead Shop:
Participating Shops: LOCKSMITH


Acct No Obj Code   %              Systems Code: 322
------- --------  ---            Related WO No:
13470   633       100

=========================================================================

Date Completed: _____________  Root Cause: ______________________________

Completion Comments: ____________________________________________________

                            Page: 1 of  1
```

cannot be postponed.

Priority 3: All works required to prevent breakdown of essential operating or housekeeping functions or to improve the operating performance of necessary systems are implemented through the work order. Following the receipt of the work request that requires action by any shop, a work order is issued to the concerned job shop. Job shops in turn plan and organize labor, material and equipment for these jobs.

STAGE III- Accounting

The generation of the work order establishes the proper information channels for accounting of this work. "Accounting of work" implies both the financial (who to charge) and personnel responsibility (who has done this work). The format of the work order is designed to document maximum information about the status of the work request. (See Exhibit 4C) The work order is indeed the most important document that can provide management with leading information, particularly after a period of time. Apart from the information available from the work requests, additional information gathered is as follows:

1) Work Classification number

2) Date completed.

3) Coordinator assigned to the project.

4) Account number to be charged for the work.

5) Certification and comments of completion by the supervisor.

The concluding act in this control process is reporting of completed work, in form of comments by the assigned mechanic. For any control system, the importance of this information, generated through the feed-back needs to be emphasized. Reporting-back allows an evaluation of the complaints (as reported by the user) and the actual situation of job.

4.6.2. PREVENTIVE MAINTENANCE SYSTEM

Preventive maintenance (PM) is as a scheduled program in which wear and tear, change in performance are anticipated, and continuous corrective actions are taken to ensure peak efficiency and minimize deterioration. (Dwyer, 1984, sec III, p 102) PM includes a variety of tasks such as maintenance, repair and replacement. All jobs are performed on a scheduled frequency as per the PM manual.

At PPD, the responsibility of implementing of the PM program is with the PM supervisors. The PM office carries out the building surveys and develops a list of the recommended items, tasks, and frequencies. This is send to the respective shop supervisor, who determines the item that need to be put on the program, the tasks to perform, and the frequency fo these tasks. (MIT, 1988) The PM office, then prepares work packages based on these recommendations for the various shifts. They are also responsible for making prior arrangements for material, equipment, shutdowns, etc., inspection of the work to be performed, and supervision. The PM offices also makes recommendations to the appropriate shop supervisor to modify requirements as they become aware of significant problems.(ibid, sec. V-A)

The PM office also coordinates the architectural and engineering services and make the PM shop supervisor before the building/ systems is handed over for operations purpose. The PM office prepare many management reports such as estimated vs actual exception report; weekly status report; vendor reports; etc.

PM is carried out on a large number of items; mechanical and electrical equipments, such as air handling units, electrical motors, fans, hot water generator, pumps; and building structure, such as door, painting, etc.

4.7 EXISTING FEEDBACK AND PERFORMANCE CONTROL

Feed-back of performance information is collected informally, by management mainly through staff and user. This use of this information is primarily for purposes of estimating the services required for prospective work. Complaints are used as an direct indicator of maintenance and repair work. While the management has a fair knowledge of problem areas of a buildings (reference to "problem areas" are often found in the SOP manual), this knowledge is not generated from a systematic analysis of historic problems. Post-operations evaluation of operations informations sometimes takes place within the concerned functional units — structural shop, mechanical shop, etc. albeit at the upper management levels for some critical items of the building inventory. One recent effort to study performance through historical data is best illustrated in project undertaken by the Support Services and Building Operations described below.

The role of the OC, is geared towards directing day-to-day maintenance and repair activities to concerned functional units. The importance of the operations center in the building operations process is that it is here that knowledge about non-performance is first known to the organization, via complaints. However, it has no play in asserting control over the building operations process in its existing role and responsibility, neither is it geared with appropriate tools for evaluation. The centralized complaint management system has to a certain extend ensured that information about non-performance is readily and easily available to the firm.

4.8 AN EFFORT TOWARD POST OPERATIONS ANALYSIS: THE ROOFING SUB-SYSTEM

In 1985, the Superintendent of Support Services and Building Operation's office undertook an ambitious project to systematically develop an inventory of various building components or sub-systems such as, roofing, ceilings, doors and venetian blinds, of all the academic buildings (except housing) on campus. The objective of this scheme was, firstly to develop a concise history of some of the most critical building components and secondly, to be able to manipulate this data for aiding repair and maintenance decisions. The program also received support due to the fact that, PPD was to implement a new computerized maintenance management system, and the prospect of benefiting from this situation seemed encouraging.

The most successful survey, in terms of completeness, accuracy, and usefulness of data collected was for the roofing sub-system. Roofing constitutes one of the largest cost components in the maintenance budget of any organization, primarily because it is the most severely exposed part in the building envelope. Recent studies on roofing have pointed out that the cause-effect relationship of roofing problems is indeed critical and warrants careful scrutiny in this area.

The surveys conducted on similar lines, for other building components were either postponed or abandoned (totally or halfway), mainly due to lack of resources available for this purpose. Furthermore, there were some serious questions at the upper level of management, regarding the perceived usefulness of this project, and other related problems regarding database management.

The roofing projects followed three steps of development:

The first step in this program was to identify and collect data from various sources for roofing. The data was gathered by two modes: by inspection of the roofing and by collecting related information from other units within PPD.

The second step in the projects was to construct it into a singular data-base. To enable this a commercial database program called Cornerstone was used. The database consisted of three primary groups:

a. Building history data, such as building type, building age, location, etc.

b. Roofing history data, such as roofing age, replacement years, roofing repair costs by year, roofing details such as roofing materials, type of insulation, flashing, deck, etc.

c. Operations data collected by the operations center and other PPD units and comprised of the history of roofing complaints by building type.

The third step was to extract a number of reports from this database (See Appendices B, C, and D). These reports were used by the building services (particularly the structural shops) to get a clear view of the status of the roofing on the campus at any given time and to request for fund for repair works.

Despite the capability of the database program, there were some inherent problems regarding use this information as a basis for studying the roofing history-- precisely for which this project was started. Some problems associated with this are clearly identifiable; there was an increasing effort required for collecting current data (which needs to be manually retrieved from operations center) and update new information on a regular basis. Furthermore, there was no appropriate method of relating the trouble calls with the problem area — an important factor for any such analysis — especially as most roofing problems are area specific.

To overcome some of these difficulties, a further development in this effort took place in the last few years. Roofing areas were systematically divided in "sectors", defined as one unit of drainage area. The basic idea of this method was to aid faster location of the roofing problems. Sector can thus; a) identify roofing areas where critical problems occur, b) associate the complaint more easily with the location, i.e. rooms or group of rooms.

Identifying complaints and roofing problems by sectors is not in fully use, however the data for 1988 show that there is a consistent effort towards it. The interface between the OC and the structural shop is still ill-defined for this purpose, and operations data retrieval for the project at present, largely a manual process.

CHAPTER 5
PERFORMANCE MANAGEMENT OF ROOFING

5.1 MAINTENANCE OF ROOF AT MIT

The repair and maintenance of all roofing are administered by the structural shop in the Support Services & Building Maintenance division in the PPD. Five kinds of tasks are undertaken to sustain the proper performance level of roofing (Poels, 1987, p. 279-280):

a. Cleaning maintenance which includes, removing of substances, objects, overgrowth from the surface of the roof.

b. Inspection, which provides the basis information for maintenance planning. It consists of recording the quality at the moment the roofing is ready.

c. Repair works for local damages and deficiencies of roof covering.

d. Complementary maintenance, consists of improving parts or layers which have come to the end of their life cycle, or adding materials in order to guarantee water resistance and durability.

e. Replacement, is carried out when from a technical viewpoint, complementary maintenance is unfeasible.

At MIT, these tasks are categorized into two kinds of works —minor and major works, both of which are handled by outside agencies. The minor work includes cleaning maintenance, inspection, miscellaneous roofing repair jobs, and often other roofing-related jobs such as changing of fume hoods, etc. Minor works are contracted out annually, to a single roofing company, which have two roofers permanently posted at the Institute daily to take care of these jobs. The major works — complementary maintenance and replacement works — are contracted out on a per-job basis through the normal bidding process. The decision whether a job should be contracted related based on the estimated cost and labor hours.

The annual budget for minor works for the fiscal year (FY) 1989 was approximately $12,000. The major works are done through the departmental accounts on an annual budget of $140,000. Apart from these, other discretionary funds are made available for roofing work, "if need arises".

5.2 THE OBJECTIVE

The objective of this analysis is to apply the model developed in chapter three for assessing the performance the roofing sub-system. Complaints are used as an indicator of the performance of the roof and the aim is to reduce the number of complaints in order to improve the performance of roof. The measure of the "control subject" i.e. complaints takes place in several forms; complaints per year, cost per complaint, etc. This analysis uses the two tests of theories described in chapter three, using past data for prioritizing, and for using current measurements from on-going building processes for process control. The objective of this study are briefly outlined below:

1. To evaluate whether trends can be established for roofing problem through analysis of historical complaints using statistical techniques.

2. To identify the roofing areas that are "outliers" in terms of there performance and thus should become management priority.

3. To establish a discerte control charts (c and u-chart) for performance control.

5.3 DATA

The analysis uses the data from various reports extracted from the Cornerstone database. Three reports form the "base data" for the analysis. A comprehensive summary or the Base Data can be found in the Appendix E. Some of the data relating to the building history has been updated and cross-referenced from other sources available at the PPD; the roofing areas have been updated from the roofing plans provided by the A/E & Construction Services at PPD and the information on building history, from the MIT Facts published by the OFMS. The three reports are as follows:

a Comprehensive report. The data containing in this report for each building is: building area, roofing area, age, year of roof replacement, contractor, and roofing material details such as insulation, deck, flashing.

b. Roofing History report by FY. The data in this report includes: labor hours (for both sheetmetal workers and roofers), total number of complaints per year, total cost per year.

c. Roofing Repair report. This report contained the repair history with description of the repair type and amount spent on the job.

A sample of these reports are included in Appendices B, C and D respectively.

The initial data-collection for these reports, was partially through field investigation and partially from operations log-books from 1980-85. From 1985 onwards and until today, the data has been collected by manually retrieving from on-going operations information. The data shows tremendous variability, that can be directly attributed to the data collecting procedures. Instances of data variability are found throughout the three reports:

For example, there is a sharp increase in the complaints registered in 1981 from its previous year by nearly 200% suggests that the data as far back as 1980 may not be available completely to the recorder. It is possible, that the increase in complaints is a result of better institutionalized procedures for recording complaints. Since January 1988, MIT has a computerized maintenance management system which allows better recording and storing procedures. Further, the management focus on this project was evident in the data for 1988. There is a clear attempt to identify roofing problems by the sectors (which was not done in the previous years).

Lack of proper categorization was evident in the Roofing Repair report. There is no clear way for judging the nature and extent of repair jobs undertaken. This can be best illustrated by some example from the database: about 20-25% of the total complaints in a buildings have no description of the type of works recorded. Similarly, some of the roofing defects have no information about location This implies that roofing works cannot be allocated to a sector. Data is recorded at varying levels - in some cases, specific descriptions of works are recorded, in some others, the type of work is barely indicative. Works performed on more than one location are also recorded on the same work order and sometimes two maintenance and repair works are done simultaneously on one work order and thus it is difficult to segregate the cost associated with each. Rapid identification of the job type with these data records is not possible.

Evidently, the contract for the minor jobs include a range of works- some relate to repair of jobs relating to the building envelop and a number of roofing related jobs.

For this analysis data was completely available for a total of 100 buildings located on the main, east and west of the campus. This data does not include any of the academic housing.

5.4 CHARECTERISTICS OF ROOFING

The data available at the PPD, was processed to yield information for the study period of time between FY 1980-FY 1988. In order to eliminate seasonal bias, the roofing complaints are considered for the entire year.

The total roofing area of 100 academic buildings is approximately 1.6 million square feet. Of these 41 buildings are on the main campus and 59 buildings are on the east and west campus. The total roofing area has some 1133 identified sectors (defined as a unit drainage area) in the total roofing area.

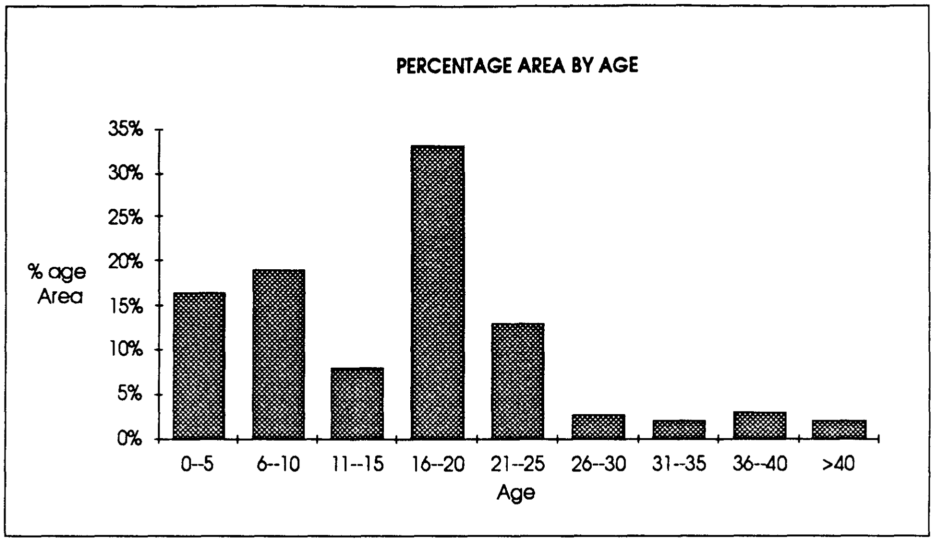


Figure 5.1a: Distribution of Roofing by Age

The average age of the roofing is approximately 19.8 years. The average age is higher in the main campus buildings with 20.73 years compared to the east and west campus, where the average age is 18.9 years. Figure 5.1 shows that distribution of the roofing area by age. This graph indicates that approximately, 33% of the total roofing area is between the ages of 16-20 yrs. Roofing between category 0-5 years constitutes about 16% of all total area and those between category 6-10 years about 18% of the total roofing area. Approximately, 1,720 square feet of roofing area has been replaced in the entire study period.

Figure 5.2 shows distribution of the roofing area by the roofing material. The majority of the roofing, i.e., 51.87% of the total roofing is of tar and gravel (T&G), 16% in asphalt. In the last few years, an increasing amount of the roofing has been replaced with Rubber. This preference for this roofing is evident, as 85% (approximately 145,200 square feet) of the roofing replaced during the study period has been with this roofing materials.

From 1980-1988, a total of 2,255 complaints have been received for roofing problems on an average of 2.5 calls/ building/ year. Of these, total

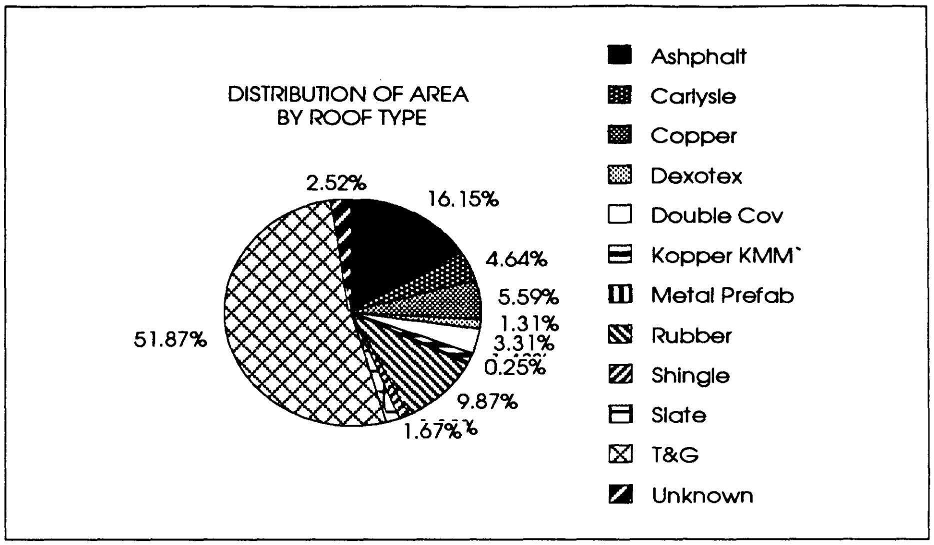
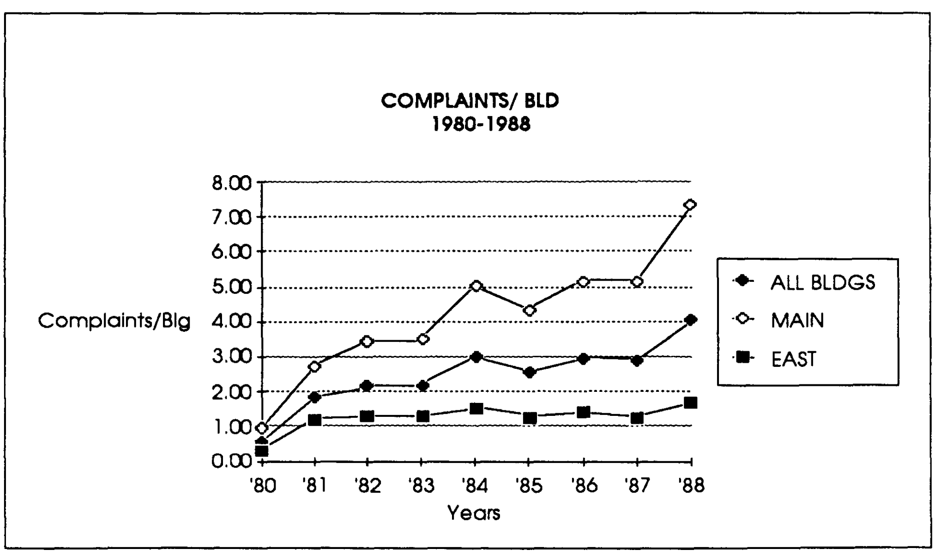


Figure 5.2: Distribution of Area by Roofing Type

number of calls, 169 calls for miscellaneous works, comprising of minor jobs carried out campus-wide and not identifiable to any particular buildings. Figure 5.3 shows the distribution of the average number of complaints per building from 1980-1988: Firstly, there is a sharp increase in the total complaints received in 1981 and 1984 over its previous fiscal years. Similarly, in 1988, 409 calls were received, an increase of 35% over

Figure 5.3: Average Number of Complaints per Buildiing, 1980-1988



its previous fiscal year. (Refer to Base Data- Appendix E) The number of complaints received for the main campus is higher that the east & west throughout the years.

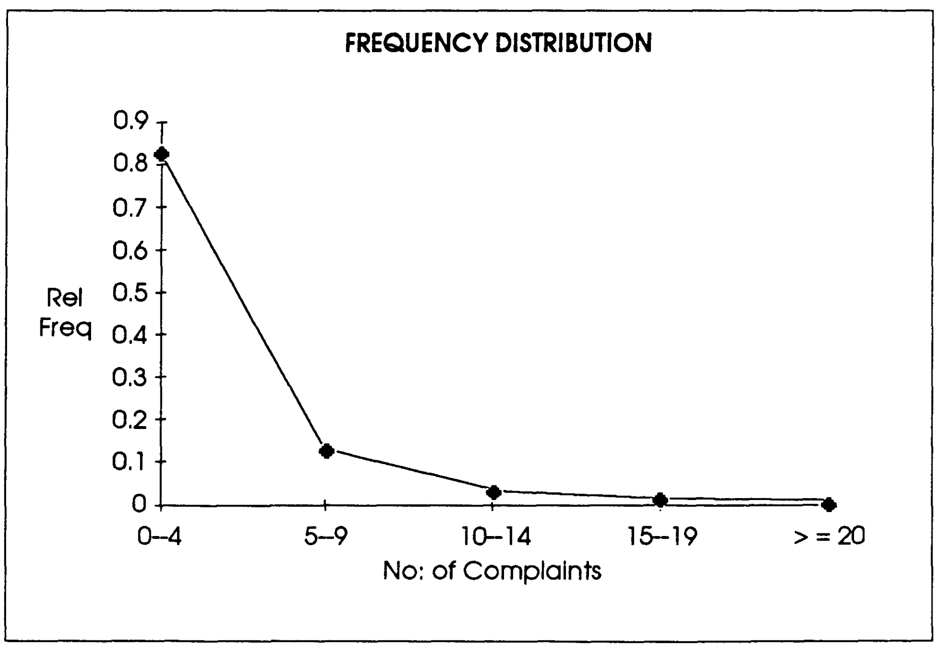
Figure 5.4 shows the frequency distribution of the complaints by number of calls. This graph shows an exponential distribution where 63.2% of the observations (building) are below the mean number of complaints as opposed to the normal distribution where 50% are below the mean number of complaints. This is substantiated by the Pareto analysis discussed in the next few paragraphs which illustrates the phenomenon of the "vital few."

5.5.1 USING PAST DATA

5.5.1 CORRELATION

To test the theories for causation between two characteristics, a number of scatter-diagram were plotted: Age versus complaints; age-area index (Note that this was one of the indices used by the PPD to assign priority on

Figure 5.4: Frequency Distribution of Complaints



jobs) and complaints. Figure 5.5 plots the repair costs with the age-area index. As evident from the graph there was no positive correlation between these factors.

5.5.2 PARETO ANALYSIS

The preliminary exercise that was undertaken, was to identify the "trivial many and vital few" through Pareto analysis. Four measures were chosen to find a subset of buildings that should become the management priority:

a. Total number of complaints.

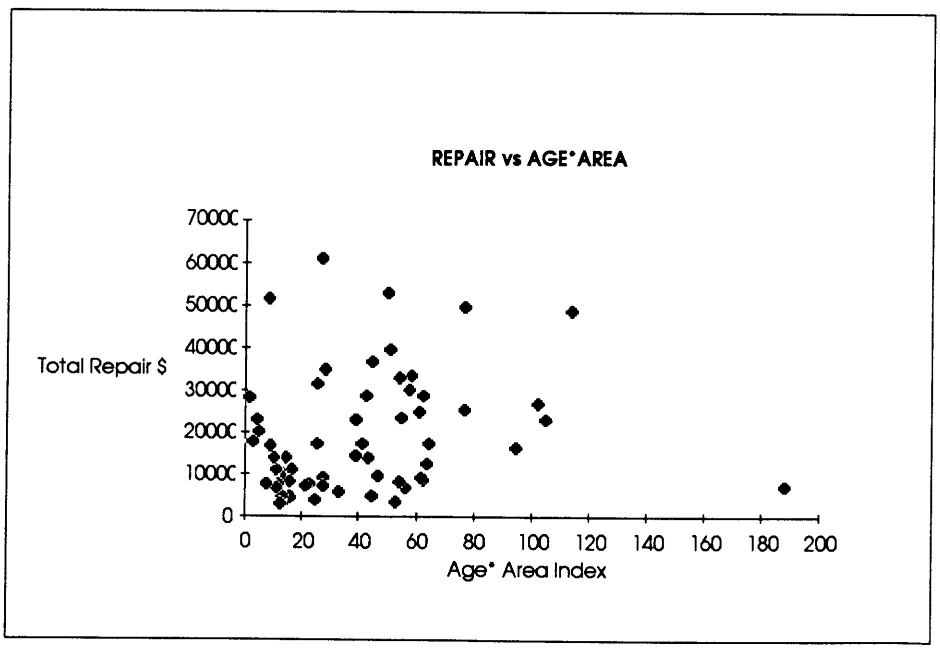
b. Complaints per square feet.

c. Total cost.

d. Cost per square feet.

Figure 5.6 shows the Pareto analysis by building type using the above

Figure 5.5: Correlations



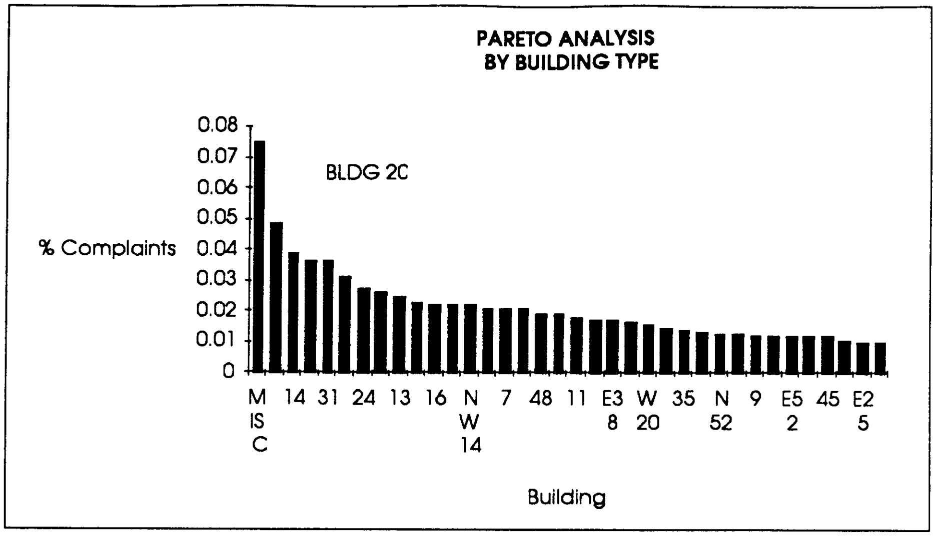


Figure 5.6: Pareto Analysis by Number of Complaints

measurements. The Pareto analysis indicates that the roofing at MIT comprises of three major groups- A,B and C

Group A comprises of the "vital few" buildings. This group comprising of 22% of all buildings (about 22 in numbers) contributed to approximately 60% of the the total roofing calls during the study period. The roofing area for there building is approximately 612,900 square feet, about 38% of the total roofing area. The repair costs are directly proportional to the number of complaints received, and thus this group also contributes to about 61% of the total cost of repair during this study period. (See Appendix E)

Group B comprises of an intermediate set of buildings, i.e. between the "vital few" and "trivial many". This group of 31 buildings (31%) contributed to about 30% of the total complaints during the study period and similarly 30% of the total replacement costs.

Group C comprises of "trivial many" buildings. About 46% of the total buildings, contributed to only 10% of all the complaints logged. Correspondingly, only 10 % of the total costs are spent on these buildings during the study period.

Building 20 ranked the highest in the total number of calls received, with an average of 12.2 complaints per year and contributed to 5.2% of the total complaints during the study period. (Note that the roofing for Building 20 was replaced in 1984) Buildings 14, 10, 31, were next highest with an average of 9-10 complaints per year. Building 14 had the highest number of 29 complaints logged in 1988. (Note that major roofing work is underway for this building) Five buildings -W53, W45, N54, E39, and E21 received no complaints during the entire study period. Figure 5.13 shows the location of the three groups of buildings on the MIT campus.

5.5.4 ANALYSIS OF TRENDS

The path that is taken up by a curve of a time series in absence of disturbing factors is known as the trend or 'secular variation." The reasons for this variation are a number of factors; seasonal, associated with weather or other annual factors; cyclical, corresponding with trade cycles or planned cycles of operations; and by unusual factors. (Chessman, 1979, p.143)

LACK OF SEASONAL VARIATIONS: Which there is no predominant period during the year were roofing problems occur, there is a slight variation in the number of complaints received per month for the study period. Figure 5.12 shows that March recorded the highest number of complaints from 1980-1988. Higher complaints were recorded in months of June, Sept and December than in months of May, July and Nov. The explanation for the substantial lack of variations is due to roofing works being undertaken throughout the year; repair works are carried out during the rain and snow months such as roof leaks, skylights, etc; and during the dry season when the roof is more accessible for cleaning, major repair jobs and replacement. It is beyond the scope of this analysis to discern the kinds of repairs conducted by month to substantiate this explanation.

TRENDS BEFORE HIGHEST COMPLAINT FOR BUILDING IS RECEIVED: Figure 5.11 and figure 5.12 show the number of complaints

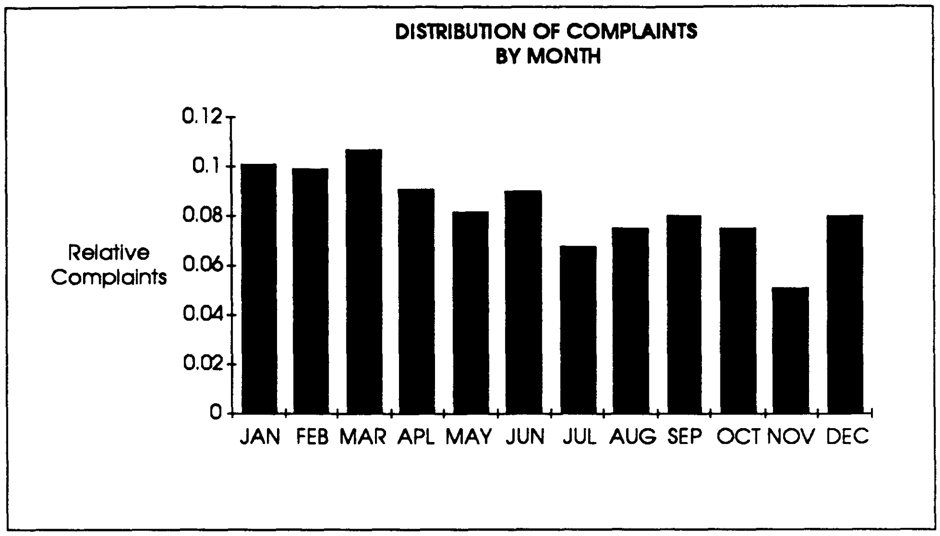


Figure 5.10 : Distrubution of Complaints by Month

received four years before the highest complaints for each building (i.e. year) were recorded. The purpose of this graph is to chart the performance behavior (via complaints) of the roof in the years before the maximum number of complaints were recorded. Figure 5.11 shows this trend for buildings 20, 14, 10, 31, 26,and 24. Four of these buildings show that firstly, there is a reduction of complaints from YR -4 (i.e.four years before highest complaint is recorded) to YR-3 (three years before highest complaint is recorded) and/or YR-4. Thence, there is a sharp increase in the number of complaints received until the highest complaint is recorded in YR 0. Figure 5.12 shows similar trend for Building 1, N14, 7, 2, E38 and 50. The possible explanation for this could be that minor and remedial works conducted on the roof when a large number of complaints is received cause the performance of the roof to improve substantially; however, this last only for a couple of years. Could this phenomenon lead us to develop leading indicators for predicting roofing performance from these trends? Do "symptoms" exist before largest roofing works are required?

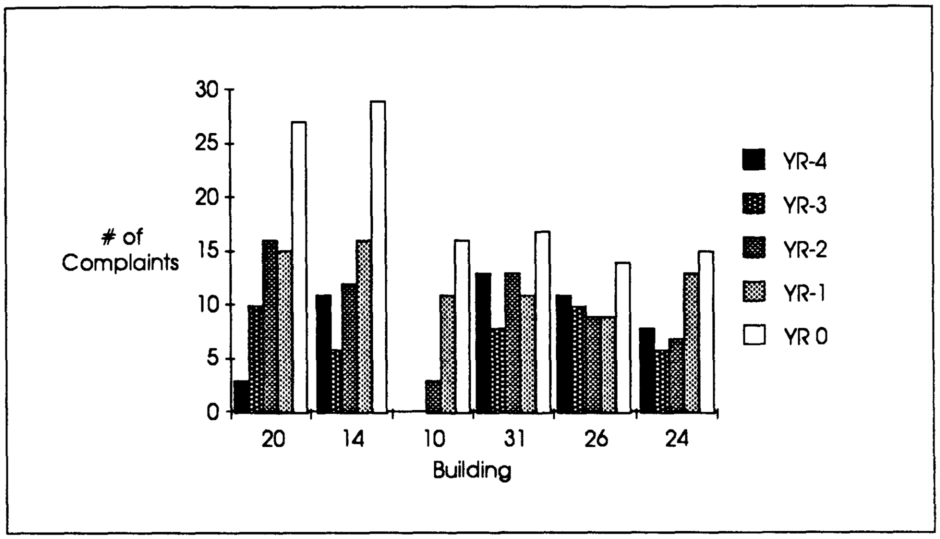


Figure 5.11: Complaint Trends

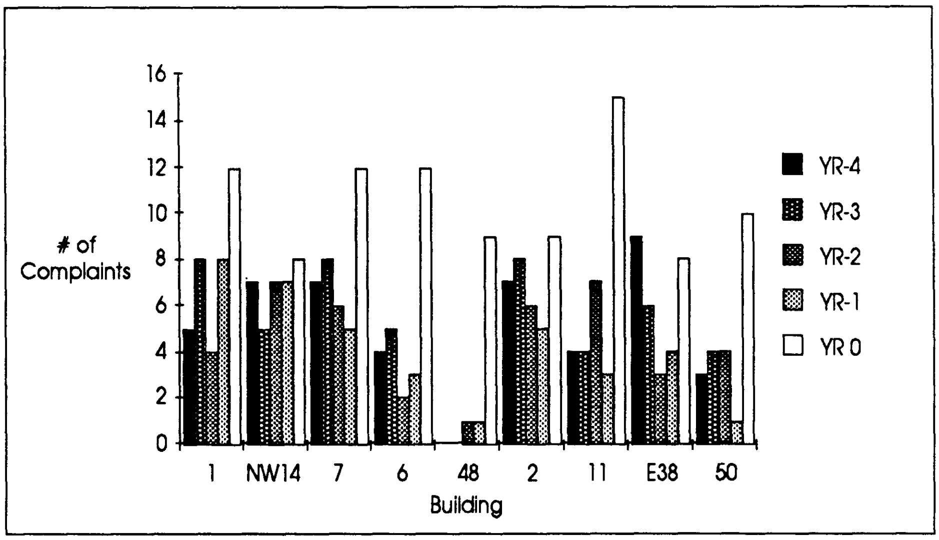
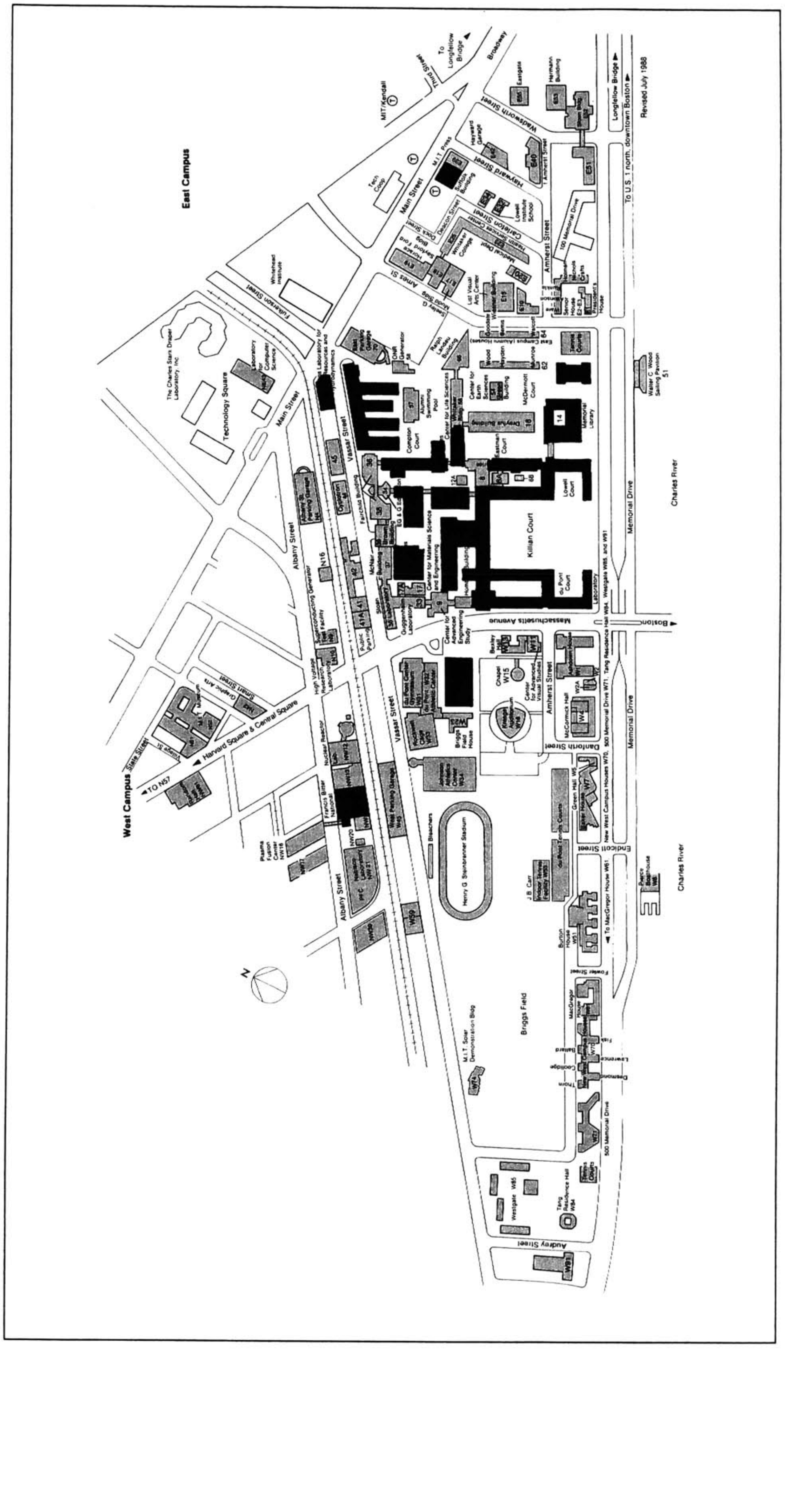


Figure 5.12: Complaint Trends

5.6 MANAGEMENT PRIORITY

Group A constitutes those buildings that should have management priority for performance management. (See Appendix F for summary of Group A buildings) The qualification for these buildings to be included in this group is that an average of four jobs are done per year during the study period. The location of the buildings is shown in Figure 5.13. Group A and group B constitute the "universal" from which management should draw the rational sub-group.

Figure 5.13: Location of Group A Buildings on MIT's Campus



5.7 APPLICATION OF A DISCRETE CHART FOR PERFORMANCE CONTROL

The model described in Chapter Three can be applied for achieve roofing performance control. Performance control is required to monitor the number of roofing complaints recorded in the study period. The sheer number of complaints received during the study period suggests that user activities are particularly sensitive to non-performance in roofing. Performance control is also required because maintenance is only meaningful if it takes place when the quality of the roofing presents technical and economic benefits.

There are two approaches to performance control, both of which have been discussed in the the introductory chapter. The first kind is required to eliminate variations in the roofing performance occurring due to assignable causes and establishing a state of "statistical control". The other is required for "breakthrough", quality improvement by undertaking advanced techniques, experimentation, etc.

By using a simple framework in form a discreet chart, performance can be monitored substantially. The control subjects here is the "roofing complaints" implying the roofing defects may occur due to a variety of problems, such as as roof leaks, water penetrations, maintenance tasks, etc. In the context of this analysis, problem-solving is at a more aggregate level, due to lack of scope in this thesis. Two discrete charts — c-chart (number of defects) and the u-chart (number of defects per unit) can be applied for this problem.

The u-chart is used to control the number of defects when the unit being inspected is not of constant size. (Note that in cases where unit in consideration is constant, the c-chart can be used. Mathematically they are both the same) In case of roofing, each building or sector has a different roof area and thus a u-chart is more appropriate. This chart is also applied when the number of defects are not the same kind as in roofing; roof leaks, blisters, ponding, skylight leaks etc. The u-chart is an extremely versatile chart. The purpose of using the u-chart for roofing is given below:

a. To determines the overall quality level of roofing.

b. To brings to attention of the management any changes in averages.

c. To locate any out-of control high values to identify bad roofing quality and similarly, any out of control low values such that this performance can be repeated.

d. To suggest places for using indiscreet charts.

e. To provide the management suitable information for future planning of maintenance and repair works.

The building operations process at the PPD (as described in chapter four) is controlled by prioritizing of various complaints received to ascertain the kinds of service response to be made. Thus, categorization of defects based on the seriousness and type of jobs is an important factor for control, To take this into account, a variation of the u-chart is used. This variation uses *demerits* per units instead of *defects* per unit. This chart type is mathematically similar to the u-chart, but instead accounts for different form of defects by assigning proper weightage to each defects (Besterfield, 1979, p. 141-143).

The central value for this can be calculated from the following formula:

Performance Indicator $U = w_1 u_1 + w_2 u_2 + w_3 u_3$

where U = demerits per unit

$w_1 \; w_2 \; w_3$ = Weights for different classes of defects

$u_1 \; u_2 \; u_3$ = Defects per unit in each of the three classes

Classification of defects: Discussion is warranted about the assignment of weightage to each of these defects. As the classification of the defects is judgmental, the management should draw up standard operating procedures for data collection in order to exclude any variations between subgroup. Two indicators that would establish the weightage are the estimated cost of the jobs and the cause-effect relationship of that defect.

Subgroup: The rational subgroup in this case is the one sector.

Data Collection: The performance measure for the roofing complaints is the number of defects/ unit recorded by the inspector. Data is collected by counting the number of defects in each category and calculating the total number of defects in each subgroup. Collection of data is assumed to be an independent process carried out on a periodic basis throughout the year. Data collection should take place more frequently before the season of rain and snow, and after the season such that control limits can be revised.

In keeping with the current developments of the roofing project in the PPD - i.e., sectors as a basis for identification- the unit (n) can be approximately 100 square feet. The area of the sector is the only additional measurement required for the control chart, which is not available at this point of time with the structural shop. There are two distinct advantage of collection defects by sectors. First, it aids data collection, i.e. counting the number of defects.for a smaller roofing area is easier than getting an approximation of say a sub-group of 10,000 square feet of roofing area. Secondly, the "vital few" sectors can be isolated by the management by Pareto analysis and can be updated subsequently as more information is available.For this analysis, the subgroup as a sector cannot be undertaken due to lack of detailed information of the complaints associated with each sectors.

The periodicity of data collection will vary, depending on the state of the process, however one month is a good estimate. At a time, a minimum of 25 sectors should be plotted at a time. The intensity of the data collection would be more before the months of March, June, September and December. For this application, an assumption is made that the rational subgroup is chosen randomly (by using random tables) from the 450 sectors in Group A.

The mean calculated for the control chart is significantly low (2 complaints / month). This means that the management has to wait a long to know about the performance of the roof. On one hand, roofing is an important part of the building inventory and is clearly a priority areas with the management. On the other, the control chart, is probably inappropriate for this application. Roofs have an estimated life cycle of 20 yrs. Roofs are particularly "slow-living" and generate information relatively fewer complaints in comparision with mechanical and other systems.

This chapter has demonstrated that SQC can be potentially applied for understanding performances of the roofing behavior from historic data. The model can also be used partially, in cased such as roofing for identifying management priority. The PPD can potentially use this information. In particular, further analysis undertaken by sectors, would help the management to focus on relatively few problem area that are the constant source of problem. These performance control of roofing by focussing on "vital few" sectors can justify inspection plans and any future developments of this model.

CHAPTER 6
CONCLUSIONS

The preceding chapters have laid the foundation for a discussion regarding adoption of the Statistical Quality Control model at Physical Plant Department (PPD) This discussion includes an overview of the current state of building operations at PPD with regards to performance management, and some strategies for implementing this model based on various issues raised in the body of the thesis.

The case study in Chapter Four described the building operations process for the academic portfolio, existing feedback processes, and existing performance control methods. Several management and organizational issues that need to be addressed for successful adoption of this model. These include: the incentive for PPD for implementing this model, given the current building management practice; the role of management for establishing priorities for performance control; the process of superimposition of the model upon the existing structure of operations; the implications on the Operations Center's (OC) role in aiding managerial action; the level of performance quality that PPD wishes to maintains based on the commitment to its users; institutionalizing these decisions into standard operating procedures.

The roofing program analyzed in Chapter Four and Five has established that systematic study of historic data yields important management information. It also raised several issues concerning the logistics of the SQC model, its advantages and limitations. If this model is to be be used for performance control of other parts of the building inventory, then strategic issues of execution need to be considered. These include: improvements required in data collection procedures; organization for data collection; the optimum information for this model; the choice of analytical techniques for use, (for example, only the first stage of the model may be needed for certain building elements).

Before embarking on recommendations, an overview of the present state of building operations, control, and feedback is warranted. The performance of the academic buildings at MIT is controlled by two methods: directly responding to user-generated information and preventive maintenance. The preventive maintenance is carried out for mainly mechanical and electrical equipments and subsystems. There are very few building components such as doors and windows on the preventive maintenance schedule. There is an enormous reliance on user-generated information such as complaints, to establish the status quo. This process is enabled by the centralized structure adopted for building operations, whereby all information about non-performance is directed towards the OC. Here, this information is prioritized and directed for action through a computerized maintenance management system. The direct implication of this centralized structure, in the context of this thesis, is that performance information—received, recorded and stored—at PPD is available to the management over a period of time. The amount of information is collected per day requires that it should be used for for feedback for better performance of the campus facilities.

At the management level, however, there is fair knowledge of "trouble areas" for some types of problems, especially those that are persistent (gathered from operations information). This information is distilled to the operations level through guidelines established in the Standard Operating Procedure manual to guide action when troubles are occuring. At the operations level, there exists even greater knowledge about building problems, amongst the maintenance crews at a very intimate level in their areas of trade or geographic area, which is informally exchanged amongst different units of the organization. within the organization. All of this information is difficult to capture, despite the level of sophistication employed to ascertain feedback. Instances of using historic information for evaluating performance behavior for a building subsystem, as in the case with roofing are not frequent within the department. Operations information, as argued and demonstrated in this thesis can be utilized to understand the historic performance of building components with a view to improve its future performance.

The role of the OC needs to be highlighted in the entire building operations process primarily because all information about non-performance is first known at the OC. The existing use of this information is strictly "responding/ directing", i.e. performance information is used to assign and prioritize operations activity. The OC works on a set rules of procedures, and this characteristics is one of the most valuable features for implementation. The suggestion here, however, is not to extend the existing role of OC into management areas, but to provide them with appropriate tools such that they can intercept performance variations and inform management.

During the implementation of the model, there is a clear delineation of the prospective role of the management and OC. The management's role is evidently in formulating and defining various statements of problem, primarily because they have the "top view" of the building portfolio and need to implementation from an economic, management and administrative standpoint. Further, their responsibility is in selecting appropriate control subjects, developing performance indicators, and evaluating results from operations.

The framework provided by SQC can be utilized to control the quality of performance at different levels of the portfolio. At the portfolio level, it can be utilized to compare the overall performance of different buildings; at the facilities level, it can be applied to compare performance of different building sub-systems; and at the operations level, it can be used to control the individual quality characteristics of building components, and/or a combination of these. In practice, SQC is typically used to effectively control other factors of the building process, such as vendor performance, in-coming material and likewise.

Reccomemdations for implementing this model abased on a collective knowledge of its operations practice and the pre-conditions related to the adaptation. These recommendations are made with a view to improve existing building management practice. They are outlined sequentially, in keeping with the framework of the model:

Qualitative Assessment of Performance Features: This is indeed the first step that PPD should take. Defining priority areas entails developing clear statements of quality projects. These can be established in two ways: first, data from OC can be used to isolate performance features for which the highest number of complaints are received. The analytical framework in the first stage of the model aids this process. There is an implicit assumption here, i.e. that of PPD's commitment in controlling the number of complaints. Using complaints is one index of performance, its limitations in its ability to indicate certain kinds of performances, have already been discussed in Chapter Three The PPD may well use other indices, for e.g. historic cost/ square foot or any other found suitable by the management. Second, some projects already outlined within individual job-shops in recent years, these can be reviewed and used to apply the model. One example amongst these was "Class room project," aimed at controlling the wear and tear of classrooms. Stage I of the model can be used to isolate the problems that occur most and a discrete chart can be set up most appropriately. This "project-oriented" approach is highly recommended by the author. Firstly, this would enable PPD to undertake quality improvements in a selective way that can be implemented in phases, with a view to economy and secondly, provide the scope for learning through future developments in the model..

The Operations Center: Amongst organizational pre-conditions of interest, the interface between the operations center with the management emerges as an important one. The interface requires that: firstly, management should provide the necessary guidelines to the operations center for the appropriate applications established in form of rule-based action for implementation of the model. Secondly, procedures should be outlined for feedback of this information from the OC to the management.

The logistics of the model is concerned with various issues in data collection, management and execution of the SQC model.

Defining data collection procedures: This is most evidently, an important area of improvement. The "project-approach" should also help the improvement in data collection because information requirements could be more clearly defined. Two approaches are suggested to the PPD. One involves data collection of quality at periodic intervals throughout the year of the application and subjects selected by the management. This includes outlining the data collection process by survey; it implies some administrative costs. In the other approach in-coming information from the OC can be directly utilized.

Integrated Data Base: At the portfolio level, there is clearly a need for integrating databases from different sources within MIT. This implies that exchange of information from other sources of origin within MIT; the Office of Facilities Management Systems; Planning Office; and Physical Plant need to be strengthened. As evident, the "base data" (See Chapter 5) is derived from several sources outside PPD. Consequentially, there are enormous efforts at updating this information presenting some disincentive in using such tools.

From a global perspective, the strategy suggested in this thesis may well be employed in other portfolio's that have similar structures and characteristics. For portfolios' of other kind, this model presents the opportunity for further variations, in accordance with their particular features. Several issues that need to be resolved in the model presents opportunities for future development, extension and modification.

APPENDICES

APPENDIX A

BUILDING OPERATIONS AT THE HOUSING DEPARTMENT

The responsibility of managing all the housing on-campus is with the director of housing and food services and his staff. There are three types of housing on the MIT Campus: a) Undergraduate single student housing, providing residential facilities for approximately 60% of the undergraduate population of 4,500 students in ten Institute houses, b) Graduate single student housing, residing 30% of the graduate student population in three houses, and c) Married student housing in two houses with a total of 406 apartments.

Building operations of these houses are conducted by the Housing Department. While the operations of the housing and food sevices is independent of the Physical Plant Department, they are closely associated with one another for exhange of services, personnel and information.

The Institute houses are dispersed on the west campus. The requirements of the three types of houses distinctly vary from one another. While the undergraduate houses are closely monitored by the house manager, the graduate and married students apartments have a weaker link with their building manager. The utilization of services in the undergraduate houses is more intense, most of them having a dining room and larger number of facilities. The task of upkeeping the building is with the respective building managers. The manager who takes all maintenance and repair decisions at the house level and consults with the housing department on larger issues. Each house has an in-house mechanic through the day, who takes care of the minor repair and maintenance works. The organization for building operations in the housing department is shown in Figure A.1.

Information about the future maintenance and repair to be come through written forms-filled out by the students or other users which are collected daily. Further, student can also report directly to the OC at the PPD

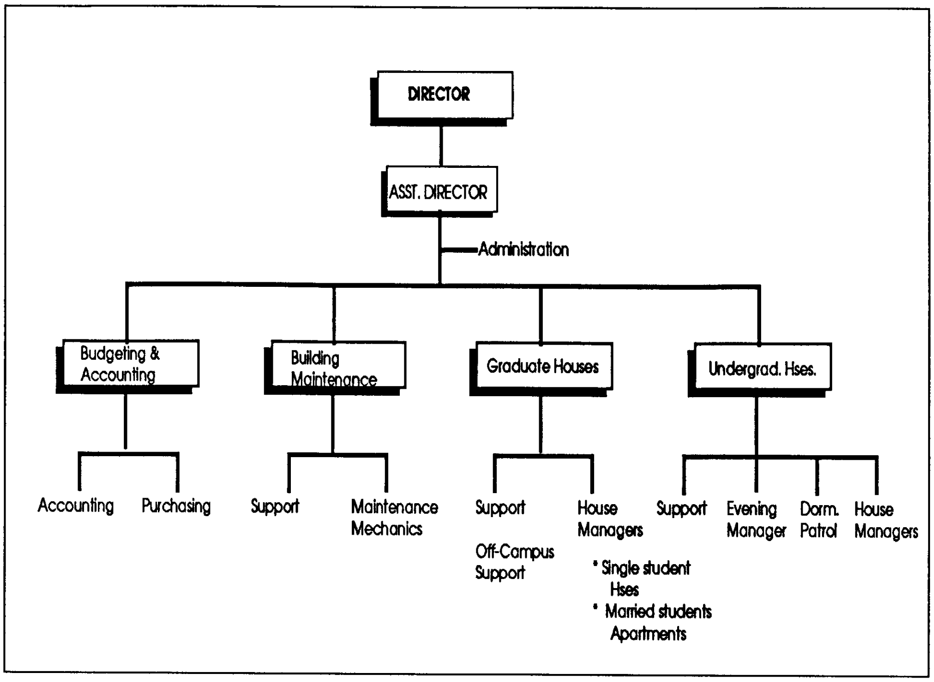


Figure A.1: Organization of Housing and Food Services Department, MIT

through the FIXIT line. Routine inspection by the house manager ensure that the performance of the facilities are kept in par with Institute standards.

After collection of complaints, three options are available with the house manager on how the work is to be conducted.

a. In-house for minor and routine repairs.

b. Physical Plant, for most mechanical and electrical shops.

c. Outside contractors, for a variety of jobs.

BUILDING NUMBER/ROOF SEGMENT
File: ROOFING MIT
Report: COMPREHENSIVE

22 JULY 19

BLDG#	YEAR	R	LOCATION	AREA	RF Y	CONTRACTOR	WARNTY	AG	REPLAC	ROOF MATERI	INSULATION	WALKWAY	FLASHING	DECK	#	YEAR	AREA	WARNTY	LOCATIO	CONTRACTOR	H	F	W	B	?
01	1916	A	ENTIRE ✓	288	1973	DUTELLE		12		ASPHALT	NONE		BUILT UP	CONCRETE							G	G			N
01	1916	B	NORTH		1967	KENNEFICI		18		ASPHALT	NONE		COPPER	CONCRETE							F	F			N
01	1916	C	SOUTH		1974	KENNEFICI		11		ASPHALT	NONE		COPPER	CONCRETE							F	F			N
02	1916	A	ENTIRE	286	1972	DUTELLE		13		ASPHALT	8-12 CINDE		BUILD UP	CONCRETE							G	G			G
02	1916	B	NORTH		1967	KENNEFICI		18		ASPHALT	8-12 CINDE		COPPER	CONCRETE							F	F			F
02	1916	C	NORTH		1974	KENNEFICI		11		ASPHALT	8-12 CINDE		COPPER	CONCRETE							F	F			F
03	1916	A	ENTIRE	310	1973	DUTELLE		12		ASPHALT	8-12 CINDE		BUILT UP/	CONCRETE							G	G			G
04	1916	A	ENTIRE	310	1973	DUTELLE		12		ASPHALT	8-12 CINDE		BUILT UP/	CONCRETE							G	G			G
04A	1937	A	ENTIRE	10	1973			12		T&G			BUILT UP/	CONCRETE							O	O			
04B	1920	A	ENTIRE	16	1958			27		T&G	1-1/2 "		COPPER	CONCRETE							P	P			W
05	1920	A	NORTH	56	1969	DUTELLE		16		ASPHALT				CONCRETE							G	P			
05	1920	B		106	1973	DUTELLE		12		T&G				CONCRETE							B	G			
06	1932	A	ENTIRE	201	1970	DUTELLE		15		T&G	1-1/2" FES			CONCRETE							G				
06A	1931	B		55	1931			54		T&G	NONE		COPPER								G	G			N
06B	1931	A	NORTH	16	1972	DUTELLE		13			1-1/2" FES														
07	1938	A	DOME	59	1963			22		LIME STONE	NONE		COPPER	LIMESTONE								F			N
07	1938	B	SOUTH	10	~~1938~~	DUTELLE	1987	47		T&G	NONE		COPPER	CONCRETE							P	F			
07	1938	C	NORTH	74	~~1969~~	~~DUTELLE~~	1992	16		T&G	NONE		COPPER	CONCRETE							G	G			
07	1938	D	EAST	37	~~1971~~	DUTELLE	1977	14		T&G	NONE		COPPER	CONCRETE							G	G			
07	1938	E	MAIN	21	~~1963~~		1977	22		T&G	NONE		COPPER	CONCRETE							F	F			
08	1916	A	ENTIRE	125	1973	DUTELLE		12		T&G	NONE			CONCRETE							G	F			
08A	1967	A	ENTIRE	10	1973			12		T&G	NONE			CONCRETE							G	G			
09	1967	A	ENTIRE	117	1973			12		T&G	1-1/2-2"		BUILT UP	CONCRETE							G	G			G
10	1916	A	DOME	76	1916			69		COPPER	NONE		COPPER	LIMESTONE								F			
10	1916	B	PIT	10	~~1974~~	~~DUTELLE~~	1988 Oak Roofing	11		~~T&G~~ Rubber	NONE		Rubber ~~COPPER~~	CONCRETE							G	G			
10	1916	C	SOUTH	98	1971	DUTELLE		14		T&G	NONE		COPPER	CONCRETE							F	G			
10	1916	D	5TH FLOOR	29	1971	DUTELLE		14		T&G	NONE		COPPER	CONCRETE							F	G			
10	1916	E	8TH FLOOR	22	1964			21		T&G	NONE		BUILT UP	CONCRETE							P	F			
11	1928	A	HIGH ROOF	5	1970			15		T&G	1-1/2"			CONCRETE							F	G			
11	1928	B	LOW ROOF	38	1971	DUTELLE		14		T&G	1-1/2"			CONCRETE							G	G			
11	1928	C		9	1971	DUTELLE		14		T&G	1-1/2"			CONCRETE							G	G			
12	1942	A	MIDDLE ROO	73	1971	DUTELLE		14		T&G	1-1/2"			CONCRETE											
12	1942	B	LOW ROOF	149	1977	DUTELLE		8		T&G	1-1/2"		LEAD COAT	CONCRETE							P	G			W
12	1942	C	HIGH ROOF	37	1971			14		T&G	1-1/2"			CONCRETE							G				
12	1942	D	PENTHOUSE	7	1981	DUTELLE		4		T&G	1-1/2" FES		COPPER	CONCRETE							G	G			
12A	1916	A	ENTIRE	11	1942			43		T&G	1-1/2"			CONCRETE							G	G			
13	1965	A	ENTIRE	366	1965			20		T&G	1-1/2" FES			CONCRETE							F	F			W
14	1950	A	NORTH	82	1965			20		T&G	1-1/2"			CONCRETE							F	F			
14	1950	B	SOUTH	171	1968			17		T&G	1-1/2"			CONCRETE							F	F			
14	1950	C	EAST	55	1965			20		T&G	1-1/2"			CONCRETE							F	F			
14	1950	D	WEST	51	1969	DUTELLE		16		T&G	1-1/2"			CONCRETE							F	F			
14	1950	E	COURTYARD	43	1950			35		FL	NONE			CONCRETE							P				
14/2	1950	F	PASSAGE TO		1979	DUTELLE		6		T&G	1-1/2"			CONCRETE											
16	1952	A	NORTH	79	1971	DUTELLE		14		T&G	3" TECTUM			TECTUM							G	G			

File: ROOFING MIT
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BLDG#	YEAR	R	LOCATION	AREA	RF Y	CONTRACTOR	WARNTY	AG	REPLAC	ROOF MATERI	INSULATION	WALKWAY	FLASHING	DECK	#	YEAR	AREA	WARNTY	LOCATIO	CONTRACTOR	R	F	W	B	I
16	1952	A	PENTHOUSE	46	1971	DUTELLE		14		T&G	3" TECTUM			TECTUM							G	G			
17	1938	A	ENTIRE	31	1938			47		T&G	1-1/2"			WOOD							G	G			
17A	1952	A	ENTIRE	15	1952			33		T&G	1-1/2"			CONCRETE							G	G			
18	1969	A	ENTIRE	179	1969			16		T&G	NONE			CONCRETE							G	G			
20	1942	A	WING A	99	1942			43		T&G	3-1/2" FIB			SHEETROCK							P	P			
20	1942	B	WING A	226	1942	1984 W.S. AIKEN		43		~~T&G~~ Rubber	3-1/2" FIB			SHEETROCK							P	P			
20	1942	C	WING A	124	1942	1985 "		43		T&G Rubber	3-1/2" FIB			SHEETROCK							P	P			
20	1942	D	WING A	74	1942	1985 "		43		~~T&G~~ Rubber	3-1/2" FIB			SHEETROCK							P	P			
20	1942	E	WING A	99	1942	1985 W.S. AIKEN		43		~~T&G~~ Rubber	3-1/2" FIB			SHEETROCK							P	P			
20	1942	F	WING A	37	1942	1984		43		~~T&G~~ Sarnafil	3-1/2" FIB			SHEETROCK							P	P			
24	1941	A	HIGH	86	1970	DUTELLE		15		T&G	1-1/2"			CONCRETE							F	G			
24	1941	B	LOW	178	1941			44		T&G	1-1/2"			WOOD							F	F			
24	1941	C	LOW	2	1941			44		T&G	1-1/2"			CONCRETE							P	P			
26	1957	A	ENTIRE	188	1973	DUTELLE		12		ASPHALT	1-1/2" FES			CONCRETE							G	G			
26	1957	B			1957			28		ASPHALT	1-1/2" FOA			CONCRETE							P	P			
26	1957	C			1957			28		ASPHALT	1-1/2" FOA			CONCRETE							P	P			
31	1928	A	CENTRAL	130	1928			57		T&G	CINDER CON			CONCRETE							G	P			
31	1940	B	EAST	57	1966			19		T&G	1-1/2"			CONCRETE							G	G			
31	1944	C	NORTHWEST	59	1970	DUTELLE		15		T&G	1-1/2"			CONCRETE							F	G			
31	1951	D	SOUTHWEST	87	1970	DUTELLE		15		T&G	1-1/2"			CONCRETE							F	G			
33	1928	A	ENTIRE	100	1971	DUTELLE		14		T&G	CINDER CON			CONCRETE							F	F			
34	1982	A	ENTIRE	40	1982	FS		3		CARLISLE ED			CARLISLE	METAL DEC							G	G			
35	1952	A		28	1952			33		T&G	1-1/2"			CONCRETE	1	1973	110			DUTELLE					
35	1952	B		110	1973	DUTELLE		12		T&G	1-1/2"			CONCRETE											
36	1973	A	ENTIRE	155	1973			12		T&G	1-1/2"			CONCRETE							G	G			
37	1967	A	ENTIRE	150	1967			18		T&G	1-1/2"			CONCRETE							G	G			
38	1973	A	ENTIRE	148	1973			12		T&G	1-1/2"			CONCRETE							G	G			
39	1968	A	ENTIRE	125	1968 84			17		T&G - Rubber	1-1/2"			CONCRETE							G	G			
41	1916	A	ENTIRE	81	1963			22		T&G	NONE			CONCRETE							P	P			
41A	1916	A	ENTIRE	110	1960			25		T&G	NONE		BUILT UP	WOOD							R	R			
42	1916	A	POWER PLAN	75	1955			30		T&G	NONE			CONCRETE							F	F			
42	1971	B	BOILER	47	1971			14		T&G				CONCRETE							F	F			
42	1967	C	CHILLER	60	1967			18		T&G	1-1/2"			CONCRETE							G	F			
42	1967	D	COOLING TO	48	1971			14		T&G	1-1/2"			CONCRETE											
42	1967	E	LINK	5	1971			14		T&G	1-1/2"			CONCRETE											
42	1967	F	FORMER 43	35	1957			28		T&G	1-1/2"			CONCRETE							F	F			
44	1938	A	WEST	82	1962			23		T&G	1-1/2"			CONCRETE							F	F			
44	1946	B	EAST	8	1962			23		T&G	1-1/2"			CONCRETE							F	F			
45	1977	A	ENTIRE	135	1977			8		ASPHALT	2" IRMA			METAL DEC							G	G			
48	1950	A	ENTIRE	108	1970			15		T&G	1-1/2"		COPPER	CONCRETE							G	G			
50	1917	A	MAIN	118	1970	DUTELLE		15		SHINGLES	NONE		COPPER	CONCRETE							G	G			
50	1917	B	NORTH	57	1917			68		T&G	NONE		COPPER	CONCRETE							F	G			
50	1917	C	SOUTH	57	1917			68		T&G	1-1/2"		COPPER/CO	CONCRETE							B,F				
51	1936	A		29	1966			19					COPPER								F	F			

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BLDG#	YEAR	R	LOCATION	AREA	RF Y	CONTRACTOR	WARNTY	AG	REPLAC	ROOF MATERI	INSULATION	WALKWAY	FLASHING	DECK	#	YEAR	AREA	WARNTY	LOCATIO	CONTRACTOR	R	F	W	B	I
N-52	1900	A	ENTIRE	209	1953 1987	J. MEDRAS		32		T&G Rubber			Rubber ~~BUILT UP~~	CONCRETE							B	B			
N-54	1900	A	ENTIRE	98	1953			32		DOUBLE COVE	NONE		BUILT UP	CONCRETE							B	B			
N-57	1900	A	ENTIRE	99	1953			32		T&G	NONE		BUILT UP	CONCRETE							B	B			
NE-40	**1964**	**M**	**ENTIRE**					//		T&G															
NE_42	**1963**	**M**	**ENTIRE**					//																	
NW-12	1937	A	PAINTED ST	58	1982	ST		3		STEEL	12" CONCRE		NONE	CONCRETE							G	N			
NW-12	1937	B		15	1973	DUTELLE		12		T&G											G				
NW-12	1937	C	HIGH ROOF	196	1970	DUTELLE		15		T&G				WOOD							F				
NW-12	1937	D		51	1970	DUTELLE		15		T&G	1-1/2"			WOOD							F				
NW-13	1917	A	ENTIRE	230	1962			23		T&G	CINDER CON		BUILT UP	CONCRETE							G	G			
NW-14	1913	A	ENTIRE	377	1962			23		T&G	1-1/2" FES		BUILT UP	CONCRETE							G	G			
NW-15	1913	A	ENTIRE	80	1962			23		ASPHALT	FIBER GLAS		BUILT UP	WOOD							F	F			
NW-16	1900	A	ENTIRE	171	1953			32		ASPHALT	NONE		BUILT UP	WOOD							F	P			
NW-17	1900	A	ENTIRE	140	1953			32																	
NW-20	1978	A	ENTIRE	20	1978			7													G				
NW-21			ENTIRE	680				//																	
NW-21		A	HIGH ROOF		1983			2		CARLYSLE ED			CARLYSLE	CONCRETE							G	G			
NW-21		B	NORTH		1953			32																	
NW-21		B	WEST		1983			2		CARLYSLE ED			CARLYSLE	WOOD							G	G			
NW-21		D	EAST		1983			2		DOUBLE COVE	NONE		BUILT UP	GYPSUM							B	B			
NW-30	1904	A	ENTIRE	259	1953			32		T&G	1-1/2"		BUILT UP	WOOD							B	B			
W-02	1900	A	HIGH ROOF	9	1971			14		ASPHALT											G	G			
W-02	1900	B	LOW ROOF	3	1971			14		ASPHALT											G	G			
W-02A	1900	A	HIGH ROOF	9	1971			14		ASPHALT											G	G			
W-02A	1900	B	LOW ROOF	3	1971			14		ASPHALT											G	G			
W-05	1901	A	ENTIRE	46	1982			3		CARLYSLE ED	1-1/2"		CARLYSLE	WOOD	1	1970	33				G	G			G
W-08	1966	A	ENTIRE	110	1969			16		T&G	1-1/2"		BUILT UP	WOOD							G	G			
W-11	1936	A	ENTIRE	71	1967			18		T&G	1-1/2"			WOOD							G	F			
W-15	1955	A	ENTIRE	30	1955			30		T&G	1-1/2"			CONCRETE							G	G			
W-16	1955	A	ENTIRE	210	1981	DUTELLE		4		COPPER	1-1/2"		COPPER	CONCRETE							G	G			
W-20	1965	A	ENTIRE	390	1965 1988	J. MEDRAS		20		~~T&G~~ Rubber	1-1/2"		Rubber ~~BUILT UP~~	CONCRETE							B	B			
W-23	1939	A	ENTIRE	87	1965			20		T&G			BUILT UP	CONCRETE							F	F			
W-31	1902	A	WEST	200	1902			83		SLATE	NONE										G	P			
W-31	1902	B	EAST HEAD	80	1972	DUTELLE		13		T&G			BUILT UP	PLYWOOD O							G	G			
W-32	1959	A	ENTIRE	213	1959			26		T&G			BUILT UP	CONCRETE							F	F			
W-33	1948	A	MAIN NEW O	333	1982	BURLINGTON		3		DOUBLE COVE	1-1/2" FES		BUILT UP	WOOD							G	G			
W-33	1948	B	UTLTY ARE	10	1966 1983	W S AIKEN		19		ASPHALT	NONE RUBBER		BUILT UP	CONCRETE							F	F			
W-34	1980	A	ENTIRE	239	~~1980~~ 1986	~~HARTFORD R~~ CHAFFIE		5		~~KOPPERS KMM~~	J P STEVENS HYPALON		KOPPERS K	METAL DEC							P	P			
W-45	1964	A	ENTIRE	5	1964			21					BUILT UP	CONCRETE							P	P			
W-53	1971	A	ENTIRE	260	1982			3		NYLON	0.1 NYLON	NONE	NONE	NYLON							G	N	N	N	N
W-53	1971	B	PATCH	4	1982	PHYSICAL P		3		DOUBLE COVE				WOOD							G	N	N	N	N
W-59		A	HIGH ROOF	70	1950			35		T&G	NONE		BUILT UP	WOOD							P	B			
W-59		B	LOW ROOF	85 [illegible]	1950			35		T&G	NONE		BUILT UP	WOOD							P	B			
W-59		C	PENTHOUSE	1 [illegible]	1950			35		T&G	NONE										P	B			

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BLDG#	YEAR	R	LOCATION	AREA	RF Y	CONTRACTOR	WARNTY	AG	REPLAC	ROOF MATERI	INSULATION	WALKWAY	FLASHING	DECK	#	YEAR	AREA	WARNTY	LOCATIO	CONTRACTOR	R	F	W	B
51	1966	B		22	1966			19					COPPER	CONCRETE							F	F		
54	1964	A	ENTIRE	58	1967	NEW ENGLAN		18		DEXOTEX	NONE		DEXOTEX	CONCRETE							B	B		
56	1965	A		39	1978	NEW ENGLAN		7		DEXOTEX	1-1/2"		DEXOTEX	CONCRETE							G	G		
56	1965	B		96	1965			20		T&G	1-1/2"			CONCRETE							G	G		
57	1940	A	ENTIRE	241	1973	DUTELLE		12		T&G	1-1/2"			CONCRETE							G	G		
57	1940	B			1940			45		T&G				CONCRETE							B	B		
58	1950	A	ENTIRE	58	1974	DUTELLE		11		T&G	1-1/2"			CONCRETE							G	G		
66	1974	A	ENTIRE	178	1974			11		T&G	1-1/2"			CONCRETE							G	G		
70	1961	A	ENTIRE	4	1961			24		T&G				CONCRETE							P	P		
E-01	1917	A	EAST	16	1969	DUTELLE		16		T&G	NONE			CONCRETE							G	G		
E-01	1917	B	WEST	16	1966	DUTELLE		19		T&G	NONE			CONCRETE							G	G		
E-01	1917	C	NORTH	18	1977	DUTELLE		8		SHINGLES	NONE			CONCRETE							G	G		
E-01	1917	D	SOUTH	5		NEW ENGLAN		//		DEXOTEX	NONE			CONCRETE							G	G		
E-10	1913	A	ENTIRE	114	1962			23		T&G	1-1/2"			WOOD							F	F		
E-15	1983	A	ENTIRE					//		Rubber											G	G		
E-17	1932	A	ENTIRE	172	1977	D. MURI EL		8		T&G	1-1/2"			CONCRETE							G	G		
E-18	1920	A	ENTIRE	172	1964	DURAN		21		T&G	1-1/2"			CONCRETE							G	G		
E-19	1920	A	ENTIRE	185	1964	DURAN		21		T&G	NONE			GYPSUM							G	G		
E-20	1920	A	ENTIRE	57	1971			14		DOUBLE COVE	1-1/2"			CONCRETE							G	G		
E-21A	1920	A	ENTIRE	7	1973			12		T&G	1-1/2"		COPPER	CONCRETE							G	G		
E-23	1982	A	ENTIRE	172	1982	HARTFORD R		3		ASPHALT	2-1/2" URE			CONCRETE							G	G		
E-25	1982	A	ENTIRE	237	1983	HARTFORD R		2		ASPHALT	2-1/2" URE			CONCRETE							G	G		
E-32	1923	A	ENTIRE	50	1970			15		T&G	NONE			CONCRETE							F	F		
E-34	1924	A	ENTIRE	50	1970			15		T&G	1-1/2"		BUILT UP	CONCRETE							P	P		
E-38		A	HIGH ROOF	53	1979	DUTELLE		6		T&G	NONE		BUILT UP	CONCRETE							G	G		
E-38		B	LOW NORTH	33	1981	ORMSBY ROO		4		T&G	1-1/2"			CONCRETE							G	G		
E-38		C	LOW SOUTHW		1981	ORMSBY ROO		4		T&G	1-1/2"			CONCRETE							G	G		
E-38		D	LOW SOUTHE		1981	ORMSBY ROO		4		T&G	1-1/2"			CONCRETE							G	G		
E-40	1930	A	ENTIRE	206	1983	BURLINGTON	Jun 88	2		T&G KOPPERS	PERLITE &		CELOTEX A								G	G	G	G
E-42	1925	A	ENTIRE	215	1952			33		T&G				CONCRETE							B	B		
E-51	1947	A	ENTIRE	188	1981			4			URETHANE		COPPER/BU	CONCRETE							G	G		G
E-52	1938	A	LOW ROOF		1970	DUTELLE		15		T&G	1-1/2"		BUILT UP	CONCRETE							G	G		
E-52	1938	A	MAIN ROOF	205	1970	DUTELLE		15		T&G	1-1/2"		BUILT UP	CONCRETE							G	G		
E-52	1938	B	PENTHOUSE		1970	DUTELLE		15		T&G	1-1/2"		BUILT UP	CONCRETE							G	G		
E-53	1965	A	ENTIRE	185	1965	1985 W.S. AIKEN		20		~~T&G~~ Rubber	1-1/2"		BUILT UP	CONCRETE							F	B		
N-04	1966	A	ENTIRE	8	1966			19					BUILT UP	CONCRETE							F	F		
N-09	1965	A	ENTIRE	42	1978			7		METAL PREFA			METAL PRE	METAL							G	G		
N-10	1965	A	ENTIRE	49	1965			20		T&G	1-1/2"			CONCRETE							G			
N-16	1972	A	COOLING TO	7	1982			3		DEXOTEX	NONE		DEXOTEX	CONCRETE							G	G		
N-16	1972	B	BRIDGE	9	1972			13		DEXOTEX	NONE		DEXOTEX	CONCRETE							P	G		
N-16	1972	C	HIGH ROOF	4	1972			13		DEXOTEX	NONE		DEXOTEX	CONCRETE							P	G		
N-16	1972	D	TOWER D	7	1972			13		DEXOTEX	NONE		DEXOTEX	CONCRETE							P	G		
N-42	1907	A	ENTIRE	116	1960	~~[illegible]~~		25		~~T&G~~ ~~[illegible]~~	1-1/2"		BUILT UP	CONCRETE							F	F		
N-51	1900	A	ENTIRE	145	1953			32		T&G	NONE		BUILT UP	CONCRETE							P	P		

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BLDG#	YEAR	R	LOCATION	AREA	RF Y	CONTRACTOR	WARNTY	AG	REPLAC	ROOF MATERI	INSULATION	WALKWAY	FLASHING	DECK	#	YEAR	AREA	WARNTY	LOCATIO	CONTRACTOR	R	F	W	B	I
W-70	1978	A	MAIN	10	1978			7		T&G			COPPER								G	G			
W-70	1980	B	ADDITION	3	1980	M.I.T.		5		GLASS	AIR SPACE		BUILT UP	GLASS							G	G			
W-74	1978	A	ENTIRE	10	1978			7																	
W-91	1948	A	HIGH ROOF	50	1948			37		T&G	1-1/2"		BUILT UP	CONCRETE							B	B			
W-91	1948	B	FR	79	1961	DUTELLE		24		ASPHALT	2" FOAM GL		BUILT UP	CONCRETE							B	B			
W-91	1948	C	MI	76	1961	DUTELLE		24		ASPHALT	2" FOAM GL		BUILT UP	CONCRETE							B	B			

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ROOFING SYSTEM REPORT
BY YEAR

BUILDING	YEAR	SMF HOURS	RFRM HOURS	TOTAL HOURS	AMOUNT	TOTAL CALLS		
03	1980	33	29	62	$ 2,136	1		
03	1981	21	21	42	$ 1,599	3		
03	1982	54	64	118	$ 4,409	6		
03	1983	62	74	136	$ 4,864	5		
03	1984	19	23	42	$ 1,618	8		
03	1985	45	51	96	$ 3,729	5		
03	1986	68	68	136	$ 5,583	9		
03	1987	40	40	80	$ 3,374	4		
BLDG: 03		342	370	712	$ 27,311	41	AVG CALLS:	5

Note : This report exhibited above is similar to the Roofing Report by Year. The report available for this analysis is by for Fiscal Year, instead of annual year.

Roofing Detail Report is structured in the following way.

Date	Description of Roofing Problem	Repair Cost
	Location, Room Number, Type of Problem,	

SUMMARY FOR ALL BUILDINGS

NO: OF BLDGS:	**100**	**AREA(SFT)**	**1,622,000**	**TOTAL COMPLAINTS**	**2086**
		SECTORS	**1133**	**AVERAGE AGE**	**19.85**

	'80	'81	'82	'83	'84	'85	'86	'87	'88
# OF COMPLAINTS	54	169	213	215	275	237	286	258	379
% CHANGE OVER PREVIOUS YEARS		213	26	0.94	27.9	-14	20.7	-9.8	46.9

	'80	'81	'82	'83	'84	'85	'86	'87	'88
AVERAGE NUMBER OF CALLS /BLDG	0.54	1.69	2.13	2.15	2.75	2.37	2.86	2.58	3.79
RANGE	4	11	17	15.00	27	13	16	16	29
SD	0.87	2.32	3.2	2.75	3.7	2.89	3.77	3.36	5.04

MAIN CAMPUS

NO: OF BLDGS:	**41**	**AREA**	**802,000**	**TOTAL COMPLAINTS**	**1411**
		SECTORS	**578**	**AVERAGE AGE**	**20.73**

	'80	'81	'82	'83	'84	'85	'86	'87	'88	
MEAN	0.83	2.34	3.32	3.34	4.49	3.93	4.93	4.44	6.805	34.415
RANGE	4	11	17	15	27	13	16	16	29	108
SD	1.05	2.88	4.25	3.47	4.94	3.5	4.68	4.01	6.084	27.028

EAST & WEST CAMPUS

NO: OF BLDGS:	**59**	**AREA**	**820,000**	**TOTAL COMPLAINTS**	**675**
		SECTORS	**555**	**AVERAGE AGE**	**18.99**

	'80	'81	'82	'83	'84	'85	'86	'87	'88
MEAN	0.34	1.24	1.31	1.32	1.54	1.29	1.42	1.29	1.695
RANGE	3	8	8	8	7	9	8	7	9
SD	0.66	1.73	1.82	1.72	1.73	1.71	2.03	2.01	2.634

BASE DATA: SUMMARY 1

COMPLAINT MATRIX

BLD. NO:	AREA (00 SQFT)	AGE YRS	# OF SEC	AGE*AREA	AREA/SEC SQFT	'80	'81	'82	'83	'84	'85	'86	'87	'88	OTAL	MEAN
20	659	5	65	32.95	10.14	3	10	16	15	27	13	10	8	8	110	12.2
14	402	28	17	113.77	23.65	1	2	3	8	11	6	12	16	29	88	9.8
10	235	21	35	49.35	6.71	3	5	10	13	8	13	11	16	3	82	9.1
31	333	23	20	76.59	16.65	3	11	17	9	6	10	12	4	10	82	9.1
26	188	16	22	30.08	8.55	2	3	9	4	11	10	9	9	14	71	7.9
24	266	19	8	50.54	33.25	2	2	2	7	8	6	7	13	15	62	6.9
4	336	17	30	57.12	11.20	0	2	4	8	4	8	16	4	13	59	6.6
13	366	12	5	43.92	73.20	1	5	2	4	10	11	7	8	9	57	6.3
12	277	22	20	60.94	13.85	1	4	6	6	6	4	8	9	8	52	5.8
16	125	20	9	25.00	13.89	2	6	9	7	5	7	7	8	0	51	5.7
1	363	16	29	58.08	12.52	4	1	5	2	5	3	7	11	12	50	5.6
NW14	377	27	34	101.79	11.09	1	3	5	8	7	5	7	7	7	50	5.6
7	201	47	9	94.47	22.33	1	1	1	8	8	3	6	12	8	48	5.3
3	336	16	35	53.76	9.60	1	2	4	8	3	8	6	8	8	48	5.3
6	272	28	8	76.16	34.00	2	4	5	4	5	2	3	12	10	47	5.2
48	108	39	13	42.12	8.31	1	1	9	3	5	4	6	7	8	44	4.9
2	363	17	33	61.71	11.00	0	2	3	3	7	8	6	5	9	43	4.8
11	52	18	2	9.36	26.00	1	3	1	3	4	4	7	3	15	41	4.6
E38	86	10	13	8.60	6.62	2	8	3	4	4	1	8	4	5	39	4.3
50	232	45	14	104.40	16.57	1	1	1	4	9	6	3	4	10	39	4.3
5	162	17	8	27.54	20.25	0	8	2	2	1	6	9	5	4	37	4.1
W20	390	1	21	3.90	18.57	3	3	2	4	5	9	2	2	6	36	4.0
NW12	320	17	18	54.40	17.78	1	4	3	2	5	1	3	5	9	33	3.7
35	138	18	12	24.84	11.50	1	3	1	0	3	3	2	4	15	32	3.6
57	241	16	12	38.56	20.08	0	2	2	2	5	2	3	4	11	31	3.4
N52	209	2	9	4.18	23.22	1	1	8	4	1	3	7	0	5	30	3.3
NW16	171	36	4	61.56	42.75	0	0	4	1	3	2	5	7	7	29	3.2
9	117	2	8	2.34	14.63	0	2	4	3	3	4	7	4	1	28	3.1
NW21	680	6	30	40.80	22.67	1	5	4	1	5	2	1	6	3	28	3.1
45	135	12	7	16.20	19.29	0	2	2	1	1	5	0	0	16	27	3.0
E18	172	25	7	43.00	24.57	0	1	7	4	2	3	3	6	1	27	3.0
E52	205	19	12	38.95	17.08	0	2	2	4	5	2	3	1	8	27	3.0
E34	50	19	4	9.50	12.50	0	2	2	3	2	4	3	5	4	25	2.8
E19	185	25	5	46.25	37.00	1	2	2	2	4	2	1	3	6	23	2.6
E25	237	2	63	4.74	3.76	0	0	0	1	4	3	4	5	6	23	2.6
56	135	20	10	27.00	13.50	1	0	2	1	3	1	2	6	4	20	2.2
E1	55	22	3	12.10	18.33	2	5	3	6	2	0	1	0	0	19	2.1
33	100	61	8	61.00	12.50	1	1	2	3	3	2	2	0	5	19	2.1
NW13	230	27	9	62.10	25.56	0	2	2	2	2	0	2	1	8	19	2.1
W31	280	67	19	187.60	14.74	0	2	0	3	2	3	7	2	0	19	2.1
18	179	18	15	32.22	11.93	1	1	7	0	3	0	0	0	6	18	2.0
W33	343	6	15	20.58	22.87	2	4	4	0	4	2	0	1	0	17	1.9
41	191	28	5	53.48	38.20	0	2	2	2	4	3	2	0	0	15	1.7
W08	110	20	10	22.00	11.00	0	5	2	3	1	0	0	0	3	14	1.6
66	178	15	9	26.70	19.78	1	0	0	0	4	2	3	1	3	14	1.6
36	155	7	8	10.85	19.38	0	2	0	2	0	3	2	2	2	13	1.4
E51	188	8	9	15.04	20.89	1	0	0	0	2	4	3	3	0	13	1.4
W32	213	30	17	63.90	12.53	1	1	0	4	3	4	0	0	0	13	1.4
51	51	23	3	11.73	17.00	0	1	1	1	0	0	1	4	4	12	1.3
54	58	22	14	12.76	4.14	0	0	0	1	1	2	0	4	4	12	1.3
W11	71	22	2	15.62	35.50	0	4	1	0	1	1	2	2	1	12	1.3
E53	185	4	6	7.40	30.83	0	0	0	3	2	4	1	1	1	12	1.3
W91	205	31	11	63.55	18.64	0	2	4	2	3	0	1	0	0	12	1.3
W34	239	3	14	7.17	17.07	0	0	3	1	2	2	2	2	0	12	1.3

8	135	18	5	24.30	27.00	0	0	0	0	1	2	3	0	5	11	1.2
E23	172	7	40	12.04	4.30	0	0	0	1	1	2	1	4	2	11	1.2
W15	30	34	4	10.20	7.50	1	4	0	0	2	1	1	0	1	10	1.1
N51	145	36	2	52.20	72.50	0	1	1	0	1	3	2	1	1	10	1.1
37	150	37	8	55.50	18.75	0	0	1	2	0	2	2	3	0	10	1.1
E40	206	6	11	12.36	18.73	0	0	0	2	1	2	4	0	0	9	1.0
E32	50	19	3	9.50	16.67	0	0	3	1	1	1	1	0	1	8	0.9
44	90	50	4	45.00	22.50	0	0	0	0	1	0	5	0	2	8	0.9
E10	114	27	9	30.78	12.67	0	1	1	2	0	2	0	2	0	8	0.9
N42	116	29	4	33.64	29.00	0	0	1	1	3	2	0	1	0	8	0.9
W59	156	39	12	60.84	13.00	1	1	1	1	3	0	1	0	0	8	0.9
W16	210	8	3	16.80	70.00	0	0	0	0	0	1	1	0	6	8	0.9
N10	49	24	2	11.76	24.50	0	2	0	1	2	0	2	0	0	7	0.8
38	148	16	10	23.68	14.80	0	2	0	0	0	1	0	3	1	7	0.8
NW30	259	36	15	93.24	17.27	0	1	1	0	0	1	3	0	1	7	0.8
N57	99	36	4	35.64	24.75	0	0	0	2	2	1	1	0	0	6	0.7
39	125	16	6	20.00	20.83	0	0	1	0	0	0	2	3	0	6	0.7
W02	9	18	NA	1.62	###	0	1	0	1	0	0	0	3	0	5	0.6
34	40	23	7	9.20	5.71	0	0	0	0	1	1	0	0	3	5	0.6
NW20	20	31	4	6.20	5.00	0	0	0	0	0	0	1	0	3	4	0.4
NW15	80	27	4	21.60	20.00	0	0	3	1	0	0	0	0	0	4	0.4
W23	87	24	8	20.88	10.88	0	1	0	0	1	2	0	0	0	4	0.4
E42	215	37	n/a	79.55	n/a	0	0	0	0	0	0	0	0	4	4	0.4
42	270	28	17	75.60	15.88	0	0	0	2	0	0	0	0	2	4	0.4
70	4	28	17	1.12	0.24	0	0	0	1	2	0	0	0	0	3	0.3
N16	27	14	12	3.78	2.25	0	1	2	0	0	0	0	0	0	3	0.3
17	46	30	2	13.80	23.00	0	0	0	0	1	0	0	0	2	3	0.3
E17	172	12	8	20.64	21.50	0	1	0	1	0	1	0	0	0	3	0.3
W01	0	0	21	0.00	0.00	0	1	0	0	0	0	0	1	0	2	0.2
N09	42	11	n/a	4.62	n/a	0	0	1	1	0	0	0	0	0	2	0.2
E20	57	18	5	10.26	11.40	0	0	1	0	1	0	0	0	0	2	0.2
58	58	15	9	8.70	6.44	0	0	0	1	1	0	0	0	0	2	0.2
NW17	140	36	7	50.40	20.00	0	0	1	0	0	0	0	1	0	2	0.2
E2	0	0	10	0.00	0.00	0	0	0	1	0	0	0	0	0	1	0.1
NE43	0	0	n/a	0.00	n/a	1	0	0	0	0	0	0	0	0	1	0.1
W76	0	0	n/a	0.00	n/a	1	0	0	0	0	0	0	0	0	1	0.1
N04	8	23	n/a	1.84	n/a	0	1	0	0	0	0	0	0	0	1	0.1
W74	10	11	n/a	1.10	n/a	0	1	0	0	0	0	0	0	0	1	0.1
W70	13	11	11	1.43	1.18	0	0	0	0	1	0	0	0	0	1	0.1
W05	46	7	n/a	3.22	n/a	0	0	0	0	1	0	0	0	0	1	0.1
E15	93	0	21	0.00	4.43	0	0	0	0	0	0	0	0	1	1	0.1
E39	0	8	n/a	0.00	n/a	0	0	0	0	0	0	0	0	0	0	0.0
N54	98	36	0	35.28	n/a	0	0	0	0	0	0	0	0	0	0	0.0
W45	5	25	n/a	1.25	n/a	0	0	0	0	0	0	0	0	0	0	0.0
E21	7	16	n/a	1.12	n/a	0	0	0	0	0	0	0	0	0	0	0.0
W53	264	7	n/a	18.48	n/a	0	0	0	0	0	0	0	0	0	0	0.0

REPAIR/REPLACEMENT COSTS ($)

BLDG NO:	'80	'81	'82	'83	'84	'85	'86	'87	'88	C TOTAL
20	4,179	8,012	9,498	10,048	10,214	8,730	5,642	3,364	1,449	61,136
14	333	743	1,731	5,106	2,743	2,453	5,486	11,183	18,946	48,724
10	1,991	4,981	5,218	9,946	5,093	5,205	7,373	12,091	1,021	52,919
31	1,843	3,828	14,561	5,644	3,689	4,726	7,490	2,550	5,379	49,710
26	1,478	4,321	14,282	1,846	7,852	5,084	4,422	4,150	8,213	51,648
24	2,813	928	533	7,101	5,843	3,899	3,742	8,034	6,969	39,862
4	0	512	1,614	4,272	2,108	3,206	10,651	2,903	5,195	30,461
13	209	4,140	1,692	2,200	5,115	5,487	3,621	4,889	9,328	36,681
12	92	1,123	4,333	1,427	2,934	1,444	4,299	7,505	1,965	25,122
16	1,101	5,505	6,481	4,263	3,303	2,988	3,832	4,108	0	31,581
1	2,714	298	4,269	969	1,332	1,317	3,611	7,883	11,129	33,522
NW14	616	1161	2745	4178	6168	3405	3764	1464	3474	26,975
7	639	327	121	4,907	2,543	374	2,488	4,373	687	16,459
3	2,135	1,168	1,450	8,252	411	3,082	2,822	6,971	6,809	33,100
6	187	1,847	2,780	1,924	1,611	1,277	2,290	8,012	5,546	25,474
48	307	308	8,063	2,184	3,346	1,956	5,018	3,668	4,104	28,954
2	0	437	3,559	1,692	5,705	4,822	5,314	3,204	4,082	28,815
11	834	5,105	233	3,430	1,948	2,862	3,241	1,999	8,928	28,580
E38	1,235	5,171	919	2,292	1,009	377	3,734	83	1,902	16,722
50	681	549	283	2,379	4,170	4,559	2,472	2,156	6,007	23,256
5	0	16,174	2,511	1,896	296	1,746	7,146	2,747	2,370	34,886
W20	3974	1805	1724	3167	4040	4800	1289	1098	1413	23,310
NW12	1065	5149	1204	596	3447	731	1616	2640	7204	23,652
35	184	3,048	702	0	448	695	938	2,745	8,824	17,584
57	0	722	1,981	1,891	2,675	985	2,356	4,361	7,968	22,939
N52	904	199	7,781	3,507	679	2,927	3,136	659	549	20,341
NW16	0	0	2475	742	1234	301	2714	3283	690	11,439
9	1,687	2,123	0	2,728	835	2,242	4,936	2,719	594	17,864
NW21	2090	4451	2041	1428	1136	1058	404	4904	0	17,512
45	0	293	1,144	459	120	2,237	0	0	6,724	10,977
E18	0	442	3,133	1,794	784	1,829	1,414	3,655	990	14,041
E52	0	1,869	1,770	3,194	1,743	1,063	1,260	164	3,384	14,447
E34	0	1,218	1,615	1,715	1,220	1,476	1,721	3,020	2,223	14,208
E19	195	558	3,515	874	1,382	456	154	1,082	1,686	9,902
E25	0	0	0	140	740	1,657	2,474	4,896	4,099	14,006
56	52	0	2,863	144	589	611	1,329	1,399	2,280	9,267
E1	583	2547	1173	5391	913	0	155	0	0	10,762
33	1,645	587	1,110	1,701	440	540	1,273	0	2,136	9,432
NW13	0	1019	345	371	575	0	449	501	5802	9,062
W31	0	860	0	2655	585	859	2136	385	0	7,480
18	264	941	4264	381	0	0	0	329	0	6,179
W33	912	4257	927	0	821	236	0	167	0	7,320
41	0	865	3,802	670	719	1,081	1,338	0	0	8,475
W08	0	3462	1132	1822	1346	0	0	0	0	7,762
66	514	0	0	3,213	690	767	0	668	1,495	7,347
36	0	1,997	0	826	0	2,169	1,269	993	693	7,947
E51	0	123	0	0	607	1,858	242	1,578	0	4,408
W32	2355	517	0	9042	1285	4261	0	0	0	17,460
51	0	691	1,093	330	0	0	647	3,271	3,668	9,700
54	0	0	0	0	65	1,174	0	312	1,730	3,281
W11	0	2065	291	0	763	1627	1172	1921	474	8,313
E53	0	0	1,778	0	857	1,526	323	163	348	4,995
W91	0	3053	4356	3248	1166	0	727	0	0	12,550
W34	0	0	3374	264	188	1225	1883	827	0	7,761

	'80	'81	'82	'83	'84	'85	'86	'87	'88	
8	0	0	0	0	669	485	1,254	0	1,782	4,190
E23	0	0	0	158	149	150	619	1,962	0	3,038
W15	781	4763	0	0	335	0	467	0	467	6,813
N51	0	356	71	292	0	1,001	1,260	652	0	3,632
37	0	0	1,060	1,009	0	1,229	2,012	1,675	0	6,985
E40	0	0	0	539	600	616	3,192	0	0	4,947
E32	0	0	6,750	10,815	1,245	361	459	0	0	19,630
44	0	0	0	228	0	3,320	0	0	990	4,538
E10	0	2,817	121	2,177	0	387	0	0	332	5,834
N42	0	0	108	108	2,335	463	0	1,081	0	4,095
W59	435	614	679	590	974	0	224	0	0	3,516
W16	0	0	0	0	0	0	242	0	1572	1,814
N10	0	1,229	0	141	2,892	0	717	0	0	4,979
38	0	1,217	0	0	0	152	0	1,081	0	2,450
NW30	0	1450	603	0	0	1007	0	0	0	3,060
N57	0	0	0	917	1,527	307	478	0	0	3,229
39	0	0	282	0	0	0	0	317	1,331	1,930
W02	0	890	0	559	0	0	0	898	0	2,347
34	0	0	0	0	1,024	309	0	0	348	1,681
NW20	0	0	0	0	0	0	156	0	0	156
NW15	0	0	1609	391	0	0	0	0	0	2,000
W23	0	613	0	0	1105	913	0	0	0	2,631
E42	0	0	0	0	0	0	0	0	546	546
42	0	0	767	0	0	0	0	0	990	1,757
70	0	0	0	151	0	301	0	0	0	452
N16	0	135	2,939	0	0	0	0	0	0	3,074
17	0	0	0	0	152	0	0	0	990	1,142
E17	0	112	0	853	0	154	0	0	0	1,119
W01	0	242	0	0	0	0	0	511	0	753
N09	0	0	164	0	74	0	0	0	0	238
E20	0	0	1,424	0	1,892	0	0	0	0	3,316
58	0	0	0	63	305	0	0	0	0	368
NW17	0	0	471	0	0	0	0	167	0	638
E2	0	0	0	0	0	0	0	0	0	0
NE43		278	0	0	0	0	0	0	0	278
W76	0	167	0	0	0	0	0	0	0	167
N04	0	1,335	0	0	0	0	0	0	0	1,335
W74	0	0	0	0	152	0	0	0	0	152
W70	0	0	0	0	0	0	0	0	0	0
W05	0	0	0	0	153	0	0	0	0	153
E15	0	0	0	0	0	0	0	0	0	
E39	0	0	0	0	0	0	0	0	0	0
N54	0	0	0	0	0	0	0	0	0	0
W45	0	0	0	0	0	0	0			0
E21										
W53	0	0	0	0	0	0	0	0	0	
Total Cost	41,027	127,717	159,517	157,240	125,108	120,545	146,893	159,421	187,825	1,225,293

COMPLAINT MATRIX

D NO:	AREA (00 SQFT)	AGE YRS	# OF SEC	AGE*AREA	AREA/SEC SQFT	'80	'81	'82	'83	'84	'85	'86	'87	'88 TC
20	659	5	65	32.95	10.14	3	10	16	15.0	27	13	10	8	8
14	402	28	17	113.77	23.65	1	2	3	8.0	11	6	12	16	29
10	235	21	35	49.35	6.71	3	5	10	13.0	8	13	11	16	3
31	333	23	20	76.59	16.65	3	11	17	9.0	6	10	12	4	10
26	188	16	22	30.08	8.55	2	3	9	4.0	11	10	9	9	14
24	266	19	8	50.54	33.25	2	2	2	7.0	8	6	7	13	15
4	336	17	30	57.12	11.20	0	2	4	8.0	4	8	16	4	13
13	366	12	5	43.92	73.20	1	5	2	4.0	10	11	7	8	9
12	277	22	20	60.94	13.85	1	4	6	6.0	6	4	8	9	8
16	125	20	9	25.00	13.89	2	6	9	7.0	5	7	7	8	0
1	363	16	29	58.08	12.52	4	1	5	2.0	5	3	7	11	12
NW14	377	27	34	101.79	11.09	1	3	5	8.0	7	5	7	7	7
7	201	47	9	94.47	22.33	1	1	1	8.0	8	3	6	12	8
3	336	16	35	53.76	9.60	1	2	4	8.0	3	8	6	8	8
6	272	28	8	76.16	34.00	2	4	5	4.0	5	2	3	12	10
48	108	39	13	42.12	8.31	1	1	9	3.0	5	4	6	7	8
2	363	17	33	61.71	11.00	0	2	3	3.0	7	8	6	5	9
11	52	18	2	9.36	26.00	1	3	1	3.0	4	4	7	3	15
E38	86	10	13	8.60	6.62	2	8	3	4.0	4	1	8	4	5
50	232	45	14	104.40	16.57	1	1	1	4.0	9	6	3	4	10
5	162	17	8	27.54	20.25	0	8	2	2.0	1	6	9	5	4
W20	390	1	21	3.90	18.57	3	3	2	4.0	5	9	2	2	6

SUMMARY FOR ALL BUILDINGS

NO: OF BLDGS:	22	AREA	612900.0	TOTAL COMPLAINTS	
		SECTORS	450.0	AVERAGE AGE	
% of All Bldg	22%	% of Total Area	38%	% of Total Complaints	
		% of Total Sectors	40%		

		'80	'81	'82	'83	'84	'85	'86	'87	'88
# OF CALLS	COMPLAINTS	35	87	119	134	159	147	169	175	211
% CHANGE			148.6	36.78	12.6	18.66	-7.55	14.97	3.55	20.57
	YR	'80	'81	'82	'83	'84	'85	'86	'87	'88
MEAN		1.59	3.95	5.41	6.09	7.23	6.68	7.68	7.95	9.59
RANGE		4.00	10.00	16.00	13.00	26.00	12.00	14.00	14.00	29.00
SD		1.10	2.95	4.54	3.41	5.11	3.37	3.21	4.03	5.75

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